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GEOSTATIONARY SPACE LAUNCH VEHICLES AND THE U.S. DILEMMA

by
William G. Clapp, Ed.D.
Major, Utah Air National Guard

A paper submitted to the Faculty of the Naval War College in partial satisfaction of the requirements of the Advanced Research Program.

The contents of this paper reflect my own personal views and are not necessarily endorsed by the Naval War College or the Department of the Navy.

Signature: William G. Clapp

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Paper directed by Professor John B. Hattendorf
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Ariane has provided an excellent "bench mark" for the U.S. to base future launch vehicle upgrades. The 198 commercial satellite launches since 1965 have provided a significant amount of data that were used to critically compare space launch vehicles. The dilemma was that U.S. space launch vehicles were found to be economically superior to Ariane for specific military payloads, but were not effective at launching commercial satellites over a wide range of payload weights. Ariane advantages were identified and low-cost recommendations have been made. If the U.S. sets the target of first equaling and then surpassing Ariane, the U.S. could once again dominate the world commercial launch market.

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The U.S. commercial space launch program no longer dominates the world and is now playing "catch-up" with the world's first commercial launch company, Arianespace. The effort to regain the lead in commercial space launch market has been hindered by declining Department of Defense budgets. President Clinton's space policy prohibits expensive new launch vehicles and limits the Department of Defense to low-cost upgrades of existing launch vehicles. The U.S. government created the space sector and has an obligation to ensure a smooth and effective split from the emerging commercial space program. Until the ties are severed, the Department of Defense must consider commercial space launch interests when making decisions.

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PREFACE

Important parameters for each launch vehicle, used to take payloads to geostationary orbit, were identified and the information was obtained through reference sources. Appendices A-J group the collected information by vehicle and were used to generate the large number of graphs used throughout the paper. A majority of the information was found in Jane's Space Directories 1988-1994. The launch vehicle costs were collected from a number of sources and all references to cost were adjusted to 1993 U.S. dollars. The launch cost for satellites delivered to a geostationary transfer orbit were calculated by taking the estimated launch cost for a particular configuration and dividing that cost by the weight of the payload. The actual individual commercial contract cost per pound rate may have been different than the estimates provided in this paper. Space launch vehicle data for 1993 was not used for trends analysis because the published data concerning recent flights was not yet complete.

WEBER STATE UNIVERSITY
OGDEN UTAH 84408-1703

DR. WILLIAM G. CLAPP
PROFESSOR
ELEC. ENGINEERING TECH.

OFFICE: (801) 626-7097
FAX: (801) 626-7578
HOME: (801) 476-9004

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DEFINITIONS

GEO

An abbreviation for the term geostationary orbit. A satellite orbit with a mean radius of 22,300 miles from the Earth. GEO satellites circle the equator every 24 hours in synchronization with the Earth's rotation and appear not to be moving.

GTO

An abbreviation for the term geostationary transfer orbit. A temporary orbit that will lead to a GEO orbit after one last booster burn. A GTO orbit is typically where space launch vehicles deliver their payloads and the satellite on-board booster completes the GEO insertion.

COMMERCIAL GEO SATELLITE

A satellite in a geostationary orbit that has been sponsored by a commercial venture and does not include those sponsored by the military or government.

COSTS

The U.S. dollars required to cover the total expenditures for launch services and provide an acceptable 5-15% profit.

CHARGES

The U.S. dollars billed to a customer whether or not they cover the actual costs. Charges are often lower than fair market prices and are offered in order to secure launch contracts.

CHAPTER I

INTRODUCTION

The U.S. space industry lost its lead in launching commercial satellites several years ago, and is falling further behind every day. The United States, for seventeen years from 1965 to 1981, launched every commercial satellite. This changed dramatically when the world's first and only commercial space launch company, Arianespace, went into business. Arianespace now dominates the commercial market by launching 65% of the world's commercial satellites. The entry of China and Japan, further reduced U.S. launches to less than 26% (Figure 1-1). An estimated $1 billion each year is lost to outside space launch competition. The demise of the U.S. commercial launch business will continue at an ever increasing rate with the emergence of the Russian commercial space launch programs and the debut of the Ariane 5. The future for U.S. commercial space launch business looks grim unless immediate corrective action is taken.

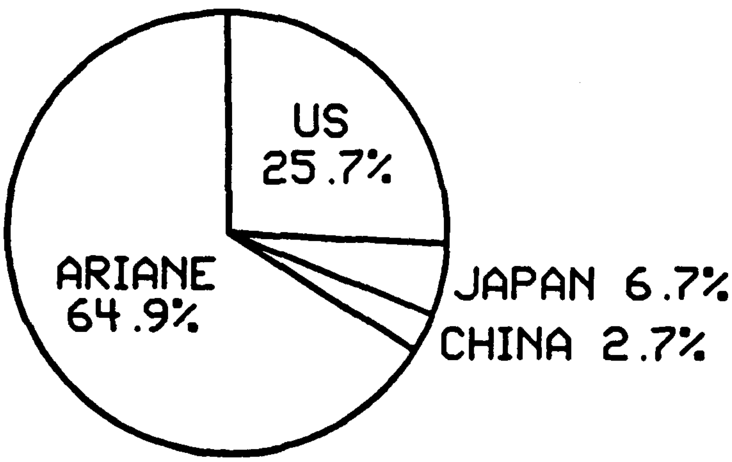

FIGURE 1. COMMERCIAL SATELLITE LAUNCHES, 1988-1992

The Problem

The problem has two parts: (1) determine why the U.S. geostationary commercial space launch program has been considered inefficient, costly and increasingly noncompetitive, and (2) make low-cost recommendations that could help U.S. commercial space launch vehicle manufacturers regain their lead.

Limitations

This paper is limited to the study of geostationary satellites because they represent nearly all of the world's commercial satellite market. Recommendations have been limited to the identification of low-cost incremental changes to the existing Atlas, Delta, and Titan geostationary U.S. space launch vehicles to help them be more competitive in the world market. Large multi-billion dollar expenditures to develop new space launch vehicles were a remote possibility and thus not considered.[1] The conversion of surplus ICBM missiles to GEO satellite launch vehicles were also not considered because they were originally designed as sub-orbital launchers for small payloads and lacked the upper stages to carry significant payloads to GTO.[2] The use of foreign space launch vehicles to place military payloads into geostationary orbit was also not considered because the problem, as defined by the Space Modernization Study Group, required a fix for the U.S. space launch program, not an alternative.

Overview

The current U.S. space launch program has been accused of being too costly, inefficient, and outdated to be competitive with Ariane and other foreign government space programs that have aggressively pursued commercial geostationary launch contracts. This study takes a step-by-step approach since payloads, launch costs and vehicle efficiencies must be clearly understood and quantified before any conclusions can be drawn. Evaluation criteria for launch costs and vehicle efficiencies were designed to facilitate comparisons between launch vehicle manufacturers. The paper was divided into five major areas of study: (1) historical perspective, (2) geostationary satellites, (3) launch vehicle costs, (4) launch vehicle selection, and (5) launch vehicle technology.

Historical Perspective

The United States has found itself involved in a number of space related races during the past 50 years. These races were motivated either by reasons of military advantage or national credibility. The only significant race for space that the U.S. won was the race to the moon. The U.S. lost or took a draw on all the other races. The races reviewed were: (1) the United States vs. Germany, the first liquid-fueled rocket, (2) the United States vs. the Soviet Union, the first satellite in orbit, and (3) the United States vs. the Soviet Union, the race to the moon.

First liquid rocket race. The development of the first liquid-fueled rockets took place with little publicity because few people understood the potential. Early German development centered around funding from a movie producer who attempted to create a rocket for a science fiction movie. The first American liquid rocket development funding also came from private venture capital. Neither the German nor American development of liquid-fueled rockets made significant advances until the military stepped in with the vision of developing long-range rockets carrying warheads. The race for development of the military rocket intensified in the thirties and the winner surfaced during World War II. A German scientist, Wernher Von Braun, was responsible for the success of the most advanced rocket weapons in the world. More than 5,000 German V2's were built and fired into England during the latter part of World War II.[3]

Although the United States lost the race to utilize rockets as a military weapon, it attempted to recover by coercing 100 German rocket scientists and technicians to come to America to continue rocket development, one of whom was Wernher Von Braun. Von Braun and many of his associates were anxious to work for the Americans.[4] Early American rocket development was hindered by administrative problems. Major General Curtis E. LeMay, representing the Army's Air Branch, urged the establishment of a single rocket development group, the Air Force, to curtail the wasteful duplication of effort by the Army, Navy, and Air Service.[5]

First satellite in space. The United States and the Soviet Union competed furiously for nearly fifty years trying to get ahead of the other in a seemingly endless race for space. The stakes were high. World prestige, honor, and military advantage were in the balance during those 50 years. But the next significant hurdle was well beyond the technology of ICBM's and required rockets with speeds in access of 18,000 miles per hour in order to hurdle satellites into orbit.

The Soviet Union launched the world's first man-made satellite in October of 1957, just weeks before the test launch of the U.S. Vanguard. The Vanguard test launch, using a dummy second and third stage, was successful, but when the full rocket, with upper stages and a satellite, was attempted six weeks later, it collapsed on the pad in flames.[6] A frustrated group of German scientists, working on ballistic missiles for the U.S. Army, pleaded for years to have the opportunity to launch a satellite.[7] Wernher Von Braun was finally afforded the opportunity to rescue the program by offering to convert a military Jupiter C, within 60 days, to launch a satellite into low-Earth orbit. The 60-day promise was kept with the launch of Explorer I on 31 January 1958. The earlier political decision that prohibited Wernher Von Braun and his U.S. military missile arsenal from assisting in the first U.S. satellite, cost the country considerable loss of time and credibility.[8] The government entered the race too late to change the outcome.

Race to the Moon. The Soviet Union achieved an early lead in placing man into orbit and that lead is evident today with the continuous manning of the Mir Space Station since the late eighties. We lost to the Soviet Union on every front and President Kennedy was the first president ever to commit the nation to such a risky and costly race for space. Just eight days after the Soviets launched the first human into space and one day after the Bay of Pigs ended in America's humiliation, President Kennedy announced the U.S. race to the moon on 25 May 1961.[9]

> I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to the Earth. No single space project in this period will be more impressive to mankind or more important for the long-range exploration of space.[10]

The race to the moon was motivated by hurt pride, a sudden fearsome imbalance of earthly power, and the vision of one man, President Kennedy, who realized that the United States could not be second in the eyes of the world, because second was last.[11] The race to the moon has been the only space race that the U.S. has won and it took a significant amount of the nation's resources, time, and will power focused on the task. The national interest in the race for the moon has seldom been matched and only exceeded by international skirmishes or wars.

The Space Modernization Study Group has been tasked with a number of responsibilities, one of them is to clearly define priorities, goals, and milestones regarding the space launch capabilities for the Department of Defense. Lt. General Thomas S. Moorman, Chairman, assembled a team of 30 people from four different sectors of the defense, intelligence, civil, and commercial community to research options concerning the future of the U.S. space launch program. The Space Modernization Study Group will present their final report to Congress in October 1994. The goals of the study were published in a Policy Letter from the Office of the Secretary of the Air Force:[12]

1. Develop a comprehensive understanding and assessment of current U.S. space-lift capabilities and environment.

2. Identify core DOD and national space-lift requirements.

3. Produce an achievable space-lift modernization road map and implementation strategy which includes: priorities, goals, decision points and funding, alternatives and options for decision makers.

4. Compare U.S. and foreign space-lift capabilities.

Previous space races were won by nations that decided the stakes were important enough to dedicate an unusually large amount of resources to ensure success. The race to the moon, the one race the U.S. won, came only after a considerable investment of time, effort and financial support. Other races were lost because the effort was insufficient to ensure success. The U.S. has typically waited for public support to mount before taking action.

Will the American people rally and demand a plan of action to regain our once-held lead in launching commercial satellites for the world? The aerospace c[illegible]y that took away our lead, Arianespace, does not represent the type of security threat that has driven other space races of past. Why should the American public care whether or not the U.S. commercial space launch business is lost to foreign competition? There are three reasons. The first, and probably most important, is the economic future of the United States. The standard of living for Americans depends on the economic health generated by successful worldwide competition. The second reason is concern for excessive expenditures of tax dollars. Military space programs consume a large amount of tax dollars and every effort should be taken to keep those costs down. Competitive commercial space launch businesses can help keep military expenditures down for those companies that take on both commercial and military contracts. The third reason is national pride, which has driven many previous space activities. President Kennedy was able to pull the nation together for the race to the moon because he believed that the United States could not be second in the eyes of the world, because second was last.[13] In summary, the American people should be concerned about the future of the U.S. commercial space launch programs because of its overall impact on our society and well-being.

Considerable political pressure has been exerted to prohibit the development of a new expensive U.S. space launch system in the foreseeable future.[14] If scarce resources are not to be used to solve this problem, then what other means might be available? This study identifies low-cost adjustments that could have a positive impact on helping U.S. space launch companies regain their lead.

End Notes

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CHAPTER II

GEOSTATIONARY SATELLITES

The sole purpose of space launch vehicles has been to take humans and/or machines outside the bounds of Earth. Their main task has been to provide short ten-minute rides to desired stellar locations. If one realizes space launch vehicles are nothing more than a product to be discarded after a few minutes, then the importance of the payload can be truly appreciated.

The U.S. once provided all commercial flights to orbit, but its share has been reduced to about 26%. Before it can reclaim the lead in providing the launch vehicles to space, its space launch providers must understand and be able to predict what the payloads of the future will look like. The significant characteristics of today's satellite payloads and those of the future must also be understood by the leaders and policy makers of the nation for them to provide proper strategic guidance for our space launch programs.

Many of the earlier low-Earth orbit satellites were designed to conduct scientific exploration, but the real impetus behind space exploitation came from nations desiring to obtain the military advantages that space could provide. Early payloads included weapons but eventually broadened to include worldwide military communications and observation platforms. The commercial use of space was slow in coming and did not occur until after the geostationary orbit became technically possible and reasonably priced.

The geostationary orbit (GEO) was found to exhibit some superior advantages not found by any other type of orbit.[1] The most significant advantage of the geostationary orbit has been that ground station receivers can be permanently aimed at the satellite, which made communications an ideal mission. GEO satellites solved the tracking problems that plagued satellites which, because of their orbits, were always moving in relation to the Earth's surface. This significant advantage also came with a disadvantage. Geostationary satellites must be positioned considerably farther from Earth than low orbiting satellites and require higher power communication circuits. Large high-gain antennas, 6-8 foot reflecting dishes, have been required to receive these weak distant geostationary satellite signals.

A geostationary orbit can only be achieved if a satellite is accelerated to a speed of about 7,000 mph in a plane aligned with the equator and a mean orbital radius of about 22,300 miles. Geostationary bound satellites are typically taken to a geostationary transfer orbit (GTO) by the space launch vehicle where they have to fire their own booster to obtain final geostationary orbit. A geostationary satellite placed into a GTO orbit still has to expend more than 50% of its own weight in propellent to achieve geostationary orbit. The Soviet-developed Proton, which takes payloads directly to GEO without the usual booster on the satellite, is an exception.

Satellite speed must be closely controlled to maintain a stable geostationary orbit; otherwise it would float east or west from its assigned position. Small thrusters are used to increase or decrease its speed, using expendable fuel designed to last from five to ten years. Battery life and fuel consumption characteristically limit the life of geostationary satellites and hence, satellites must be periodically replaced when the fuel is consumed or the batteries have deteriorated. Satellites with depleted fuel supplies or diminished system capability have typically been maintained in a standby mode for emergency use or parked out of the way above GEO altitudes.

The first satellites to achieve geostationary orbit were funded by the U.S. Department of Defense and were used experimentally to explore the potential of geostationary orbits. A large number of military satellites were placed into geostationary orbit in the mid-sixties. These early military satellites lacked adequate control to remain in a fixed spot over the Earth and hence floated east or west about 30 degrees per day. When one of the many satellites malfunctioned, another would eventually drift into position. This constellation was soon replaced with more advanced satellites that could remain on station.

The most notable geostationary satellite launch was the world's first commercial communications satellite, Intelsat 1, which was launched into a geostationary orbit over the Atlantic Ocean by a Titan space launch vehicle on 6 April 1965. Intelsat 1 provided 240 telephone circuits or one TV signal between the American and European continents.

Between the first military geostationary satellite launch in 1965, and the end of 1992 (28 years), 392 satellites were positioned in the GEO narrow band above the Earth. Over the years, geostationary satellites have grown significantly in size, weight, and capability (Figure 2-1). One half of the these, 198, have been commercial satellites that have steadily taken a larger share of the total each year. The number of commercial satellites in orbit has steadily increased to an average of 15, from 1988 to 1992.

Military geostationary satellites have leveled off at about 10 satellites per year while commercial satellites have edged up to three-quarters of all geostationary satellites launched per year. Surges in the numbers of commercial satellites occurred

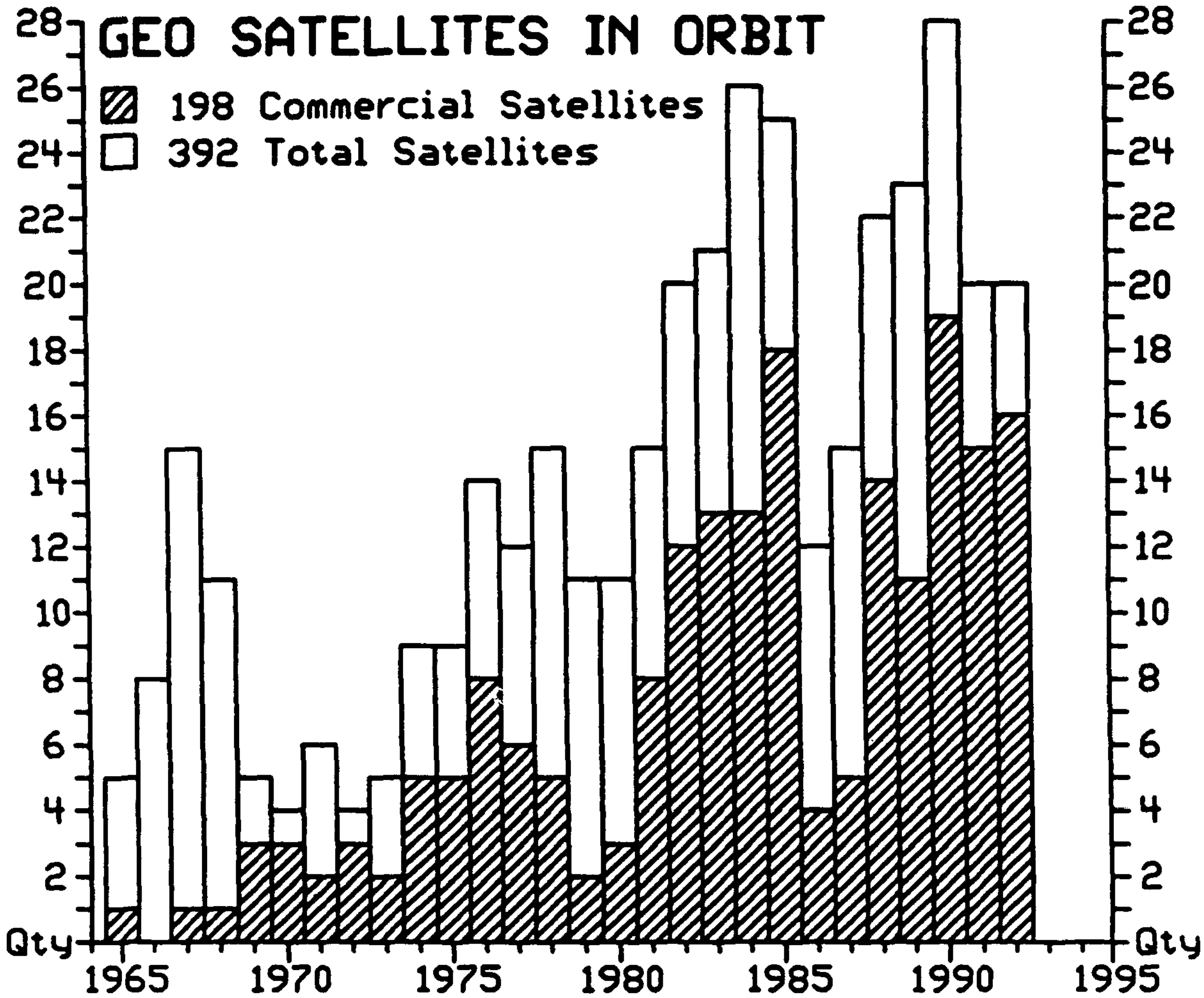

FIGURE 2-1. GEO SATELLITES IN ORBIT, 1965-1992

every seven years which may be attributed to the cyclic replacement of satellites. The USSR did not start launching geostationary satellites until the mid-seventies and partly explained the significant increases during this time period. The significant two-year drop in satellite launches in 1986 and 1987, was attributed to the Shuttle Challenger disaster.

U.S. Launched Geostationary Satellites

United States Government and U.S. commercial space launch vehicle companies have been responsible for the launching of 216 of the total 392 geostationary satellites that have been placed into orbit through 1992 (Figure 2-2). The large number of U.S. military geostationary satellites has fallen off to about two per year. The significant drop in satellites launched in 1986-1989 was due the Shuttle disaster in 1986. The accident prompted an immediate change in policy to reduce the backlog of satellites while the Shuttle was grounded. Expendable space launch vehicles made a relatively strong comeback but still fell short of the numbers experienced in previous years.

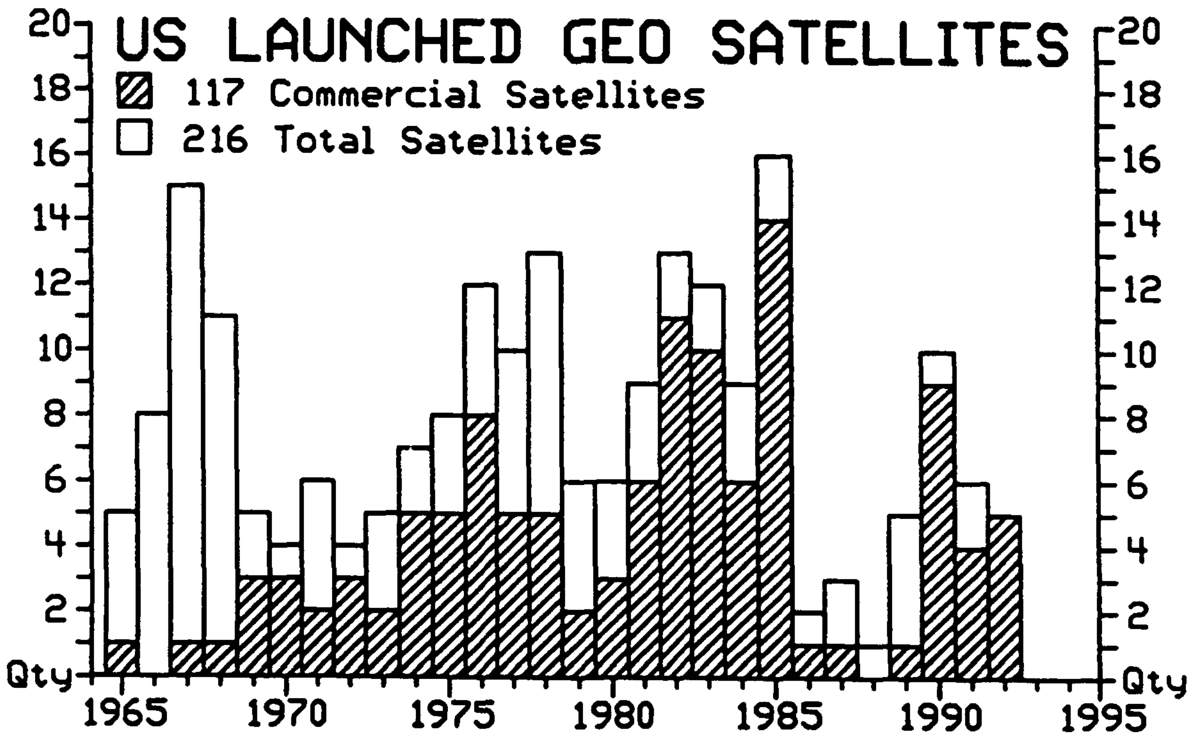

FIGURE 2-2. U.S. LAUNCHED GEO SATELLITES

Ariane Launched Geostationary Satellites

Arianespace was the first commercial space transportation company in the world and was formed in 1980 by 36 leading European manufacturers of aerospace and electronics equipment, together with 13 major European banks and the French National Space Agency (CNES).[2] Ariane has launched 66 of the 198, or one-third, of all the world's geostationary satellites in a short twelve-year period. Ariane now delivers an average of 10 satellites per year to geostationary orbit (Figure 2-3). Ariane rockets have typically carried two satellites which allows them to launch two different sized satellites (up to their maximum takeoff weight) and still offer a low launch cost. Ariane has been averaging twice as many payloads to GEO as the U.S.

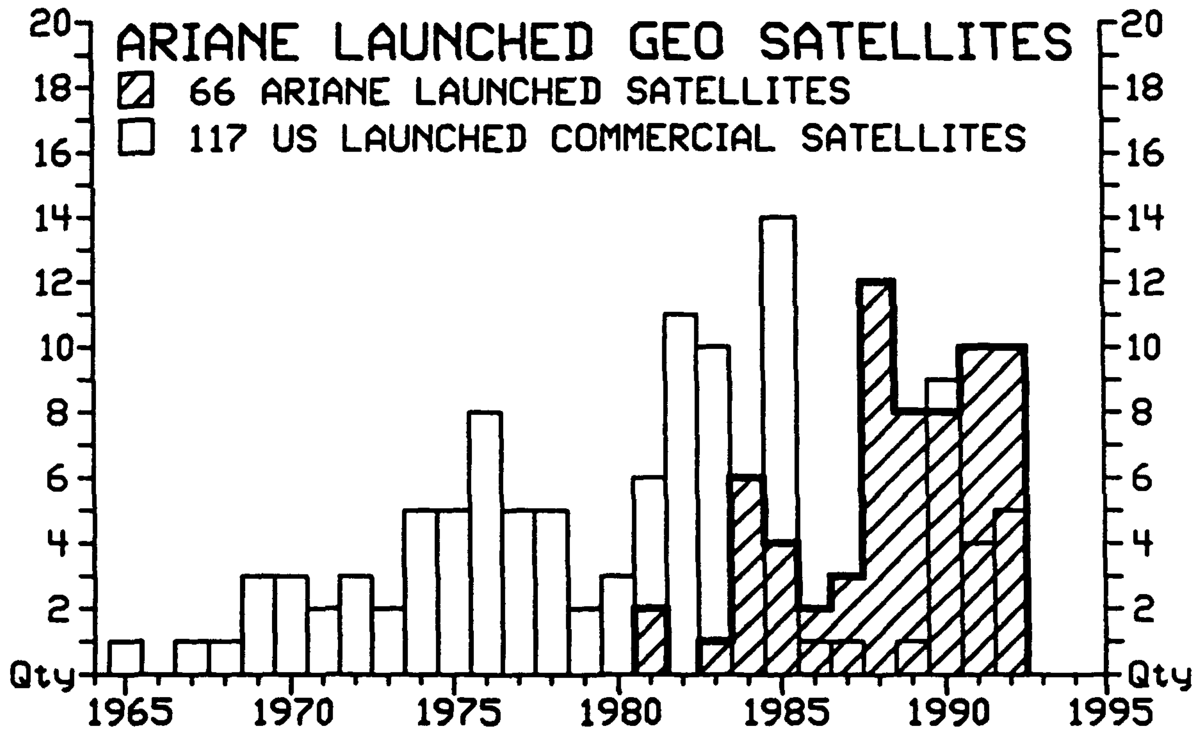

FIGURE 2-3. ARIANE LAUNCHED GEO SATELLITES

Japanese Launched Geostationary Satellites

The first Japanese GEO satellite was launched in 1977 and was sponsored by its National Space Development Agency (NASDA). The original Japanese launch vehicles (N1/N2) were McDonnell Douglas Delta stages built under a 1969 U.S. licensing agreement that prohibited third party satellites from being launched. Japan launched 13 of their own satellites into GEO between 1977 and 1992 (Figure 2-4). NASDA averaged two flights per year with half of those going to GEO. The hybrid H1, a mix of American and Japanese design, has been used exclusively since 1986 for all of its launches. The Japanese successfully launched their first all-Japanese H2 on 4 February 1994, and have broken free of U.S. restrictions.[3]

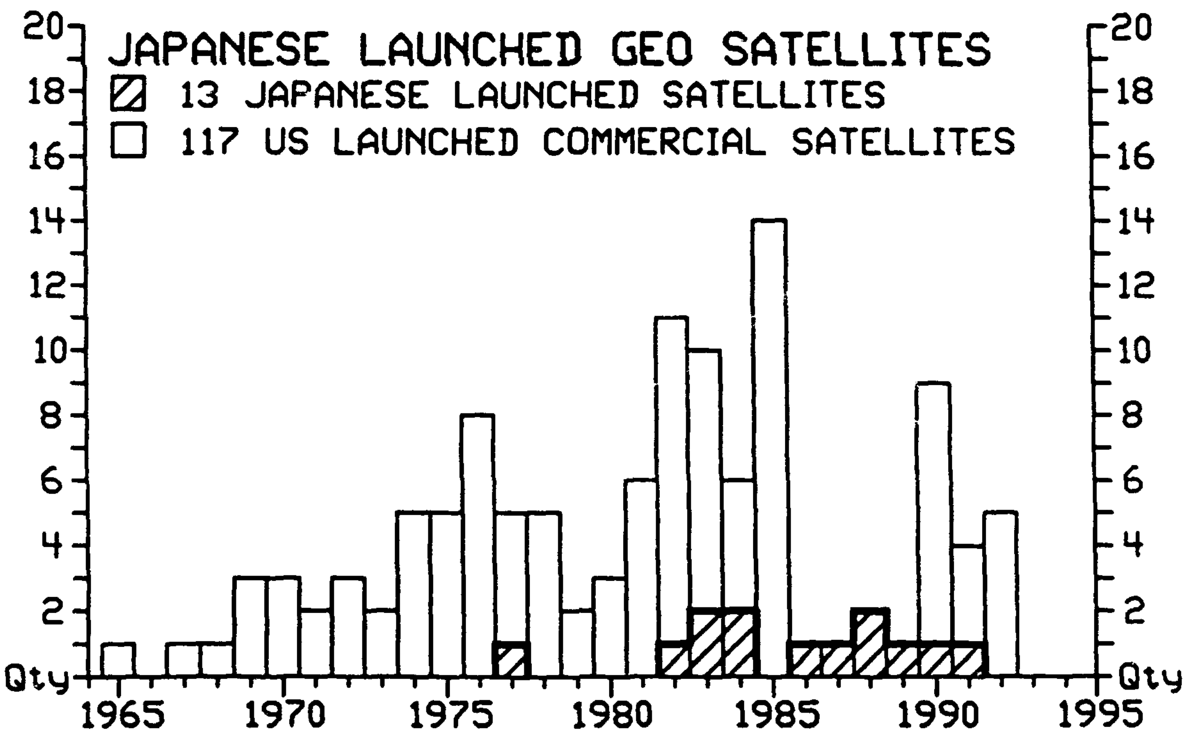

FIGURE 2-4. JAPANESE LAUNCHED GEO SATELLITES

Chinese Launched Geostationary Satellites

China launched its first GEO satellite using the CZ-3 (Chang Zheng = Long March) into orbit on 8 April 1984, three months after the failure of its first attempt. China launched seven GEO satellites between 1984 and 1992 (Figure 2-5). Commercial marketing began in October of 1985, but actual launches were delayed for five years due to concerns over unfair pricing standards. The first commercial GEO satellite was Hong Kong's AsiaSat 1 in 1990, using the powerful CZ-2E vehicle. China agreed to increase its prices and limit the number of international satellites launched (to nine) between 1988 and 1994, but export bans of U.S. manufactured satellites have delayed launches due to China's internal disturbances and disregard of international missile proliferation.[4]

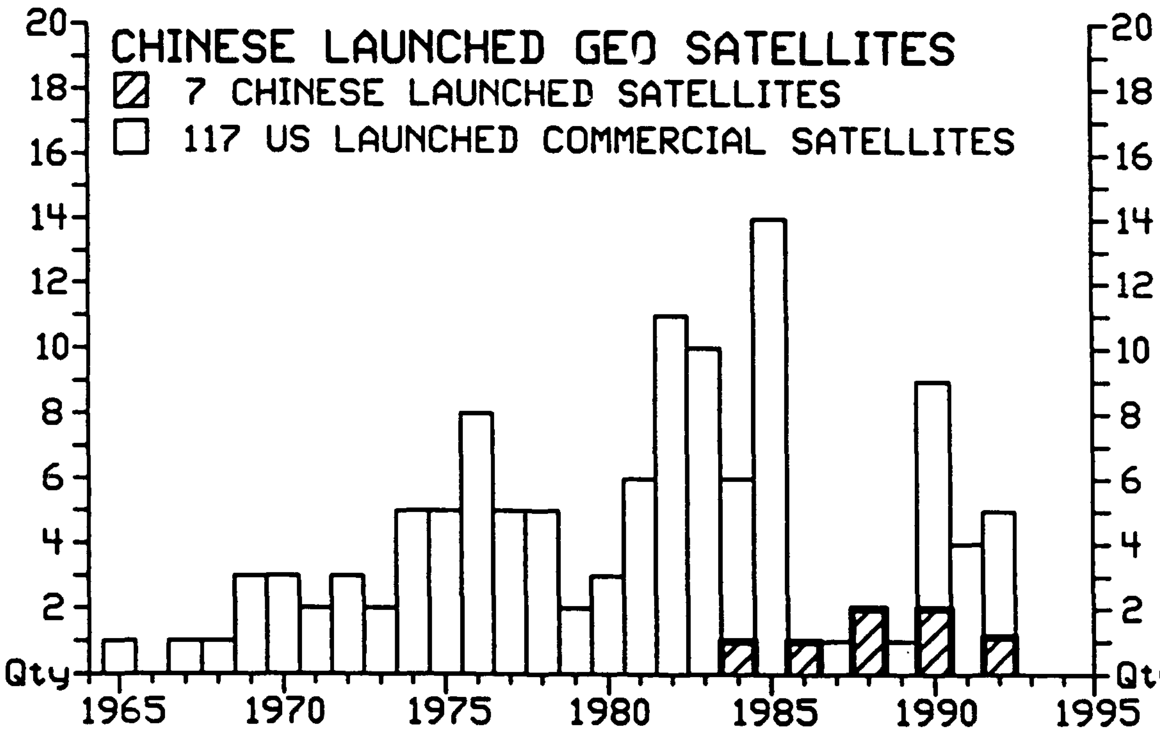

FIGURE 2-5. CHINESE LAUNCHED GEO SATELLITES.

CIS Launched GEO Satellites

The genesis of the Commonwealth of Independent States space launch program was, of course, the Soviet space program. Its first launches were experimental but were soon followed by Raduga 1 on 22 December 1975. All of the Soviet/CIS GEO satellite launches up to 1992 have used the Proton space launch vehicle. The newer Zenit is equally lift-capable and will eventually be used for commercial launches of international GEO satellites. The Soviet/CIS program launched 90 GEO satellites, both military and government, between 1974 and 1992 (Figure 2-6). The launches steadily increased until the mid-eighties, but have dropped off in the nineties. The U.S. has limited export of U.S. manufactured GEO satellites to the CIS to two a year through the year 2000.[5]

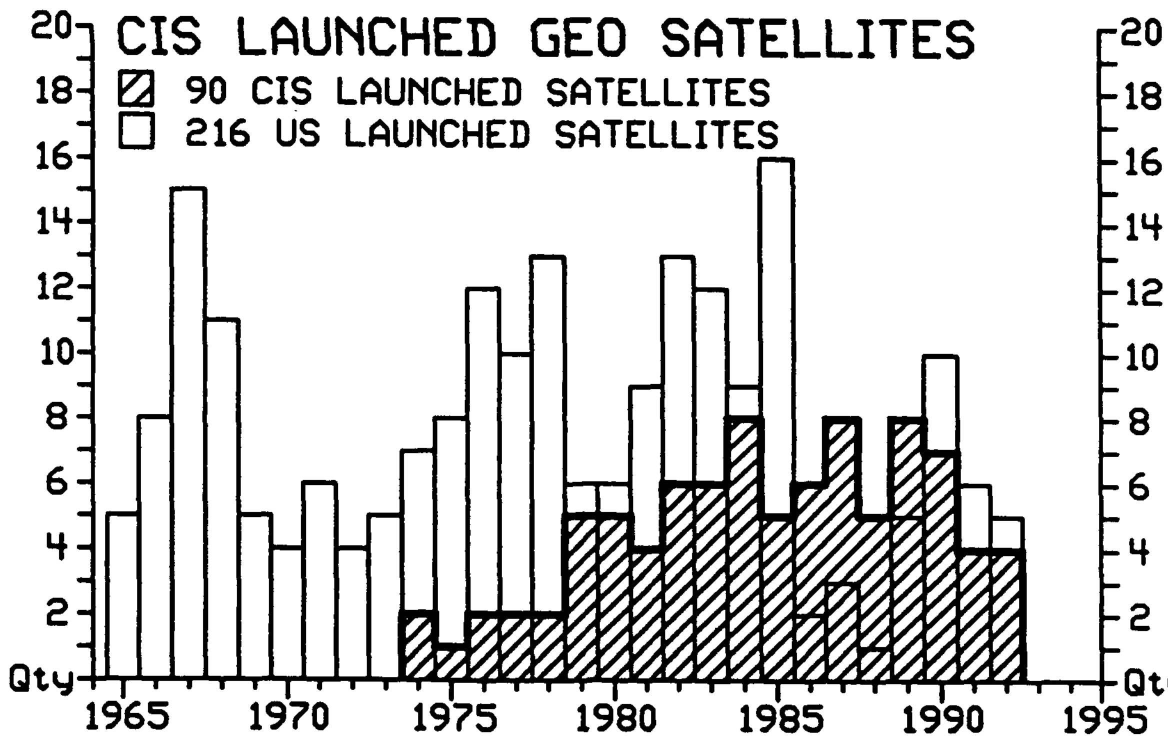

FIGURE 2-6. CIS LAUNCHED GEO SATELLITES

Geostationary Satellite Weight

The size and weight of geostationary satellites has consistently grown since 1965. The early military GEO satellites launched by the U.S. in the mid-sixties were small 45 kg satellites with small solar panels for power generation and no attitude control system for orbit stabilization. The communications circuits were underpowered because the solar panels were small compared to the ones used on GEO satellites today. Although the lack of attitude control systems greatly reduced the weight of the satellites, these early satellites were subject to drift.

The minimum weight of satellites has steadily increased to an average of 400 kg (1000 lbs), whereas, the maximum average weight leveled off at 2500 kg (5500 lbs), 1986-1992. The average weight of GEO satellites is about 1400 kg (3000 lbs) from 1987 to 1992 (Figure 2-7). The significant increase in weight from 1975 can be attributed to the addition of large Soviet GEO satellites.

Commercial GEO Satellite Weight

Commercial GEO satellites were generally lighter than military and Soviet/CIS satellites (Figure 2-8). Military and Soviet/CIS GEO satellites have been excluded from the list of commercial satellites, because both the military and the Soviet/CIS were forced to use their own countries space launch vehicles, which made them non-competitive for commercial launch. Commercial GEO satellite manufacturers have recently built and launched a number of larger 2600 kg (5733 lb) satellites.

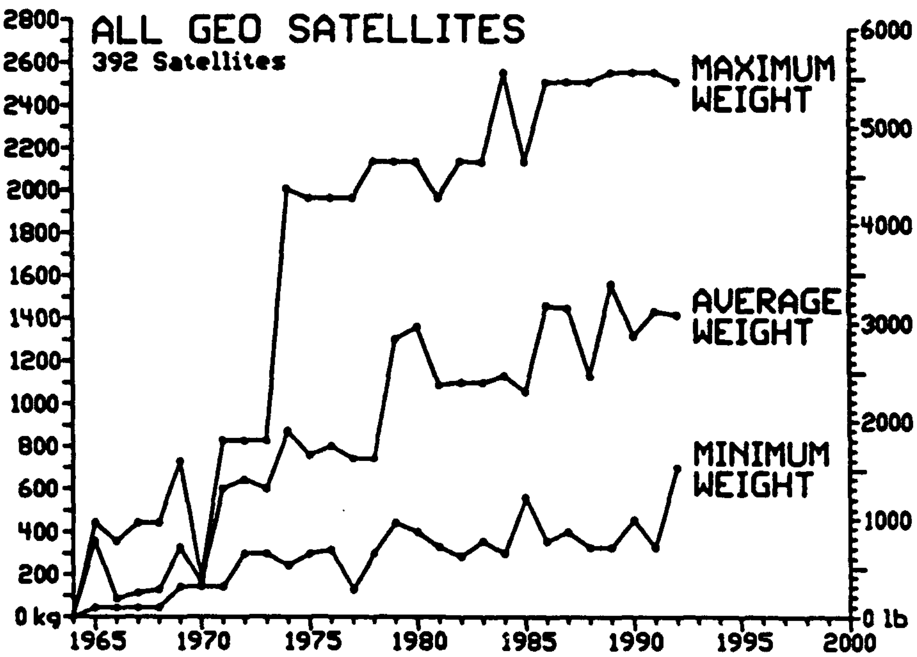

FIGURE 2-7. ALL GEO SATELLITE WEIGHTS, 1965-1992

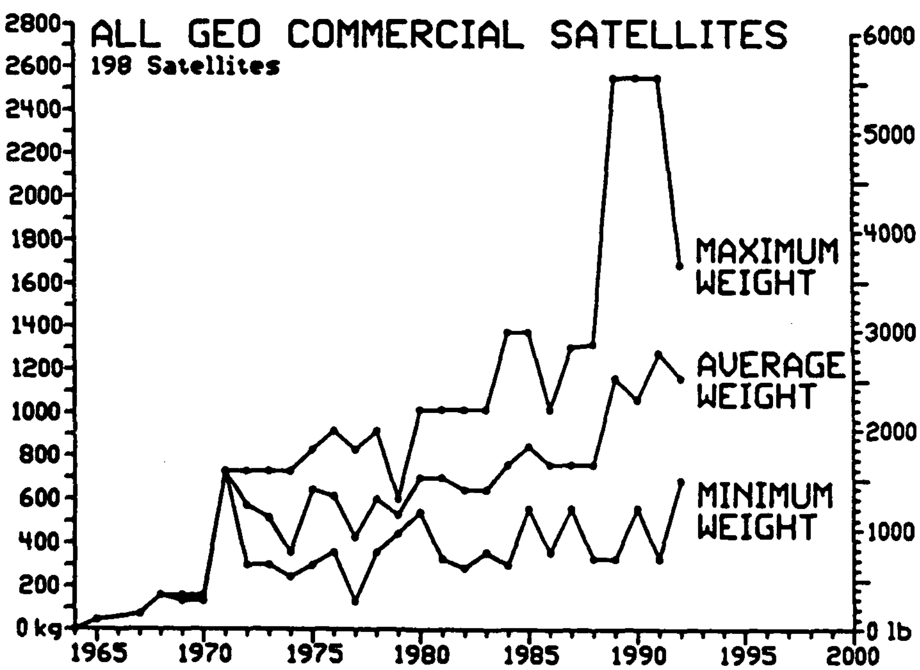

FIGURE 2-8. GEO COMMERCIAL SATELLITE WEIGHTS, 1965-1992

Arianespace has pressed forward with plans for their larger Ariane 5 in anticipation of growing satellite weight and size which will allow it to continue capturing the commercial GEO market. The Ariane 5 will be able to carry up to three satellites to GEO providing a significant advantage over U.S. space launch vehicles.

A typical commercial GEO satellite has carried about 25 percent of their on-station weight in fuel for the attitude control systems used to point the antennas toward Earth and move the satellite east or west across the sky. A five to ten year useful life has been realized using good fuel management techniques. The size of the solar panels on GEO satellites have been the significant limiting factor for the amount of signal strength that could be transmitted to ground receivers. Larger solar panels allowed satellite transmitter power to be increased, which allowed ground receiver dishes to be reduced in size. Hence, the cost for each ground station has been reduced and marketability increased. The costs for larger satellites have been easily recovered because ground station size and costs were markedly reduced while maintaining capability. The goal for satellite companies has been to push the size and weight limits of space launch vehicles.

A new technology has recently been introduced to the Telstar 401 that has made it the most powerful and most advanced commercial communications satellite in existence.[6] TV signals were typically transmitted to the Earth as analog signals. The new Telstar 401, launched 17 December 1993 from an Atlas 2AS, was designed to transmit digital TV signals which have greatly reduced power requirements.[7] If digital satellite transmission systems become widely accepted, then future satellite weight increases may be stalled.

Launch Vehicle Percentages for GEO Satellites

The 392 GEO satellites placed into orbit between 1965 and 1992 reviewed in this study include all military, government, and commercial satellites, whether operational or not. Less than half of these satellites are still considered operational, but all of them will remain in orbit for centuries to come. As noted, 216 (or 55%) were placed into orbit by U.S. manufactured space launch vehicles (Figure 2-9). The USSR or Commonwealth of Independent States placed 90 (or 23%) into orbit and Arianespace placed 66 (or 17%) into orbit. Japan and China delivered a small number of satellites into GEO, which represented 3.3% and 1.7% respectively.

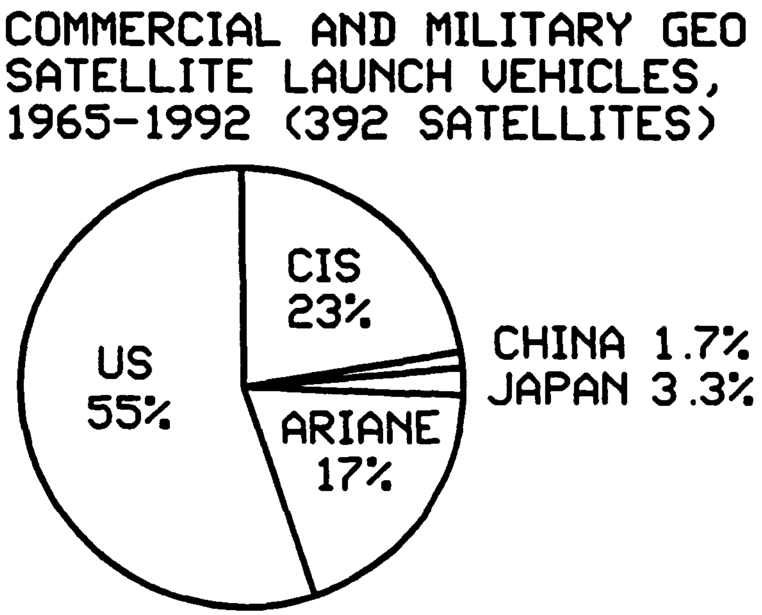

FIGURE 2-9. GEO SATELLITE LAUNCH VEHICLES, 1965-1992

Launch Vehicle Percentages for Commercial GEO Satellites

Half or 198 of the 392 GEO satellites in orbit are commercial satellites launched by the U.S., Ariane, Japan, or China. The U.S. placed 117 satellites (or 59%). Ariane delivered 66 (or 33%), Japan placed 13 satellites (or 7%) and China launched 7 satellites to GEO, but only two of these were classified as commercial launches because of their closed market for their own satellites (Figure 2-10).

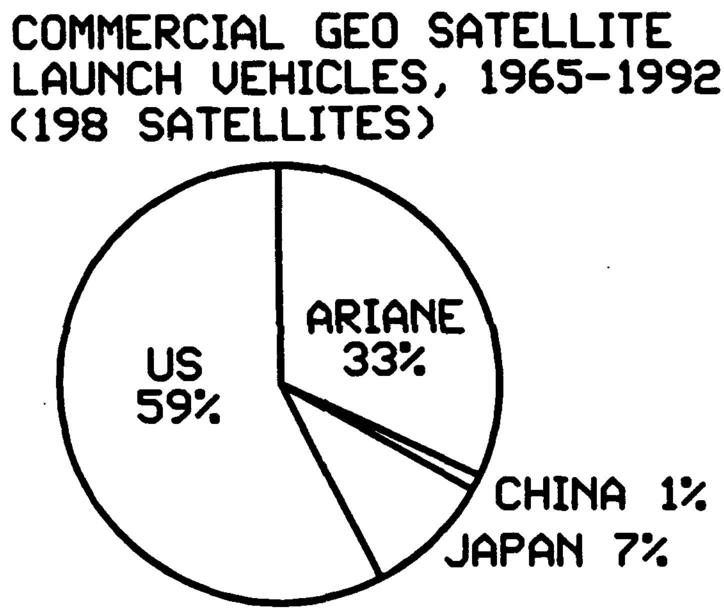

FIGURE 2-10. COMMERCIAL GEO SATELLITE LAUNCHES

Commercial GEO Satellite Launch Vehicles, 1988-1992

Ariane has taken a significant lead in the number of GEO satellites placed in orbit. In the five years, 1988 to 1992, Ariane placed 49 of the total 74 commercial satellites into orbit (or 65.3%) using considerably fewer vehicles because of of their multiple launch capability. Percentages seen in congressional reports showing that the U.S. still has 35% of the launch market misrepresents the correct picture because those statistics were based on the number of launch vehicles used instead of the number of satellites placed into orbit (Figure 2-11). The U.S. launch of GEO satellites dropped to 19 of the total 75 satellites (or 25.3%). Japanese space launch vehicles delivered five satellites to GEO to claim 6.7%. Both of the Chinese space launch vehicles (or 2.7%) were launched during this period.

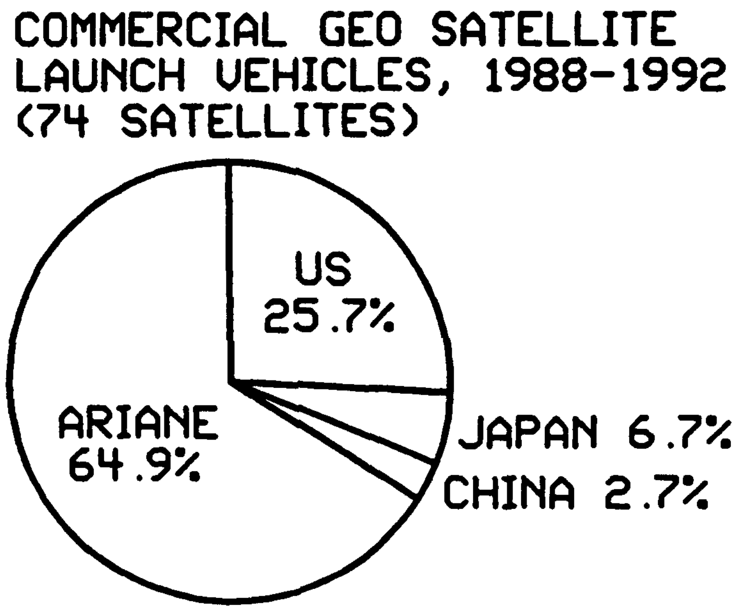

FIGURE 2-11. COMMERCIAL SATELLITE LAUNCH VEHICLES, 1988-1992

Geostationary Satellite Conclusions

Arianespace will continue to deliver most of the world's commercial satellites to geostationary orbit for the remainder of this decade and the next unless the U.S. takes corrective action. Geostationary satellites varied considerably in weight from one manufacturer to the next. Satellite designers have not typically selected a launch vehicle company until after the initial design phase has been completed. The initial design phase reveals the approximate size and weight required to perform the mission. Satellite designers then commit to a space launch vehicle about three years before the anticipated launch. Maximum capacities of the launch vehicle would then become a key factor to any future changes in design. Because of Ariane's popularity as a launch vehicle, satellite designers may have developed a tendency to make early design decisions favoring Ariane launch vehicle capabilities.

Geostationary satellites have steadily grown in size and weight because of transmitter power increases required by the commercial market. Larger solar panels are needed to accommodate power increases and expanded channel capacity. Breakthroughs in circuit design may temporarily slow down the rate of size and weight increases seen over the last 28 years. Conversion to digital instead of analog transmissions may also further reduce power requirements. A considerable savings in weight for each satellite could be achieved, but the tendency in the past has been to increase capability rather than reduce weight.

End Notes

1. Clapp, William G., "Space Fundamentals for the War Fighter." Unpublished Research Paper, U.S. Naval War College, Newport, RI: 1994, p. 12.

2. "Ariane, The European Launcher," 5th Edition: Arianespace, May 1990, p. 24.

3. Bulloch, Chris. "Japan's H2: the High Cost of Independence." Interavia, March 1994, p. 61.

4. Jane's Space Directory, 1993-94. (Jane's Information Group: Surrey, UK), 1993, p. 221.

5. Jane's Space Directory, 1994-95. (Jane's Information Group: Surrey, UK), 1993, p. 232.

6. "Atlas 2AS Launches First AT&T Telstar 4," Aviation Week & Space Technology, 10 January 1994, p. 27.

7. "Satellites: No Wires, No Cables," The Providence Sunday Journal, 3 April 1994, p. F1.

CHAPTER III

SPACE LAUNCH VEHICLE COSTS

The selection of a space launch vehicle company has been similar to the selection process of a trucking firm to transport freight. A number of minimum acceptable standards had to be met before that company became one of the many companies from which to select. A few of the minimum acceptable standards for space launch vehicles have been:

1. Could the launch vehicle handle the size and weight of the payload?
2. Would the launch vehicle over-stress the payload while obtaining orbit?
3. Could the launch vehicle deliver the payload to an acceptable location?
4. What were the odds that the launch vehicle would make it into orbit?
5. If the launch vehicle failed, what would be the warranty?

If a space launch vehicle company met all of the minimum standards, then the selection decision became one of cost.

The difference between costs and charges for launch contracts can be understood when dealing with government subsidized space organizations. The definition of "cost" is the dollars required to cover the total cost for the launch services plus an acceptable 5-15% profit. The term "charge" relates to the dollars billed to a customer for launch services, charges do not necessarily cover the expenses incurred. Charges are used to obtain the contracts. For example, the Russians and Chinese have been offering prices that cannot be matched by others because they are subsidized by government sources. United States space launch companies have tried to stop foreign space launch subsidy pricing by complaining to the U.S. Trade Representative, who can, and has, restricted U.S. satellite exports to these countries. Nevertheless, U.S. expendable launch vehicle companies have benefited from a form of subsidy from military contracts for the initial development of their launch vehicles.[1]

A 1993 United States and Russian pact allows only eight commercial geostationary launches by the Russian Proton space launch vehicle to the year 2000.[2] The agreement provides that Russian launcher pricing, terms and conditions will be "similar to" to those from other market economy countries. Launch charges that were more than 7.5 percent below the lowest offer from the U.S. and Western Europe would not be allowed.[3]

China began marketing their space launch vehicles in 1985, but have been accused of unfair pricing policies. A 1988 agreement between the U.S. and China prohibited the Chinese from launching more than nine international satellites by the end of 1994. The U.S. temporarily prohibited the export of three U.S. made satellites to China because of a concern for human rights abuses and disregard for missile proliferation protocols.[4]

The U.S. has also been accused of unfair subsidies. The Shuttle manned space launch vehicle has been a NASA government funded and operated program. The costs for launching the Shuttle have always exceeded any compensation that could have been collected for launching satellites. Shuttle costs have been about $375 million per flight. Before the Challenger accident, NASA was charging $86 million for dedicated use of the Shuttle bay and $25 million for launching a GTO satellite, when Ariane costs were running $25-30 million. Political pressure from the space launch vehicle community, in 1988, convinced President Reagan to prohibit commercial geostationary satellite launches from the Shuttle.[5]

Ariane GEO Launch Costs

Arianespace's goal is to launch half of the world's commercial satellites.[6] That goal will soon be realized if current trends continue. Ariane has a significant advantage over other space launch vehicles because of the number of different launch configurations available to match payload weights. They offer the broadest range of payload weight compared to any other space launch vehicle family. Ariane 4 has been the dominate launch vehicle and older models (1, 2, and 3) have been phased out of production. Sixteen different launch configurations of the Ariane 4 have been available to the customer, depending on the payload size and weight. They have attached either liquid or solid propellant strap-on boosters to the side of the basic Ariane 4, which provided a number of options to maximize the payload-to-orbit weight ratios. For example, in the Ariane 44L, the first number "4" identifies it as part of the Ariane 4 family, the second "4" means that there are 4 strap-on boosters attached to the side of the basic Ariane 4, and the letter "L" means that the strap-on boosters are liquid-fueled engines.

Each of the five launch vehicles (42P, 44P, 42L, 44LP, and 44L) also use an extended upper stage (H10+) to increase payload capacity. Each of these configurations can carry either a single or double payload to orbit. The multiple launch capability has greatly enhanced the opportunities to match two payloads and insure that the maximum payload weight has been obtained for the lowest dollar per pound. The lowest rate was obtained on the smallest version of the Ariane 4, the 42P (Figure 3-1). The cost per pound was $11,255 to geostationary transfer orbit, if the maximum weight capacity was utilized, 2740 kg (6042 lbs). The cost per pound increased along with increasing payload capacity, up to the largest Ariane 44L configuration. The cost per pound for the 44L was $12,711 with the maximum payload of 4460 kg (9834 lbs). In Figure 3-1, the diagonal lines represent increased costs, when the vehicle had to fly with less than maximum payload. Nevertheless, because of the many configurations, which allowed the space launch vehicle to be customized to the payload, any weight satellite (300-4450 kg) could be launched for a reasonable cost. The Ariane 5, with its increased lift capacity, will have rates as low as $7,500 per pound for payloads up to 6800 kg (14994 lb). The dual and triple

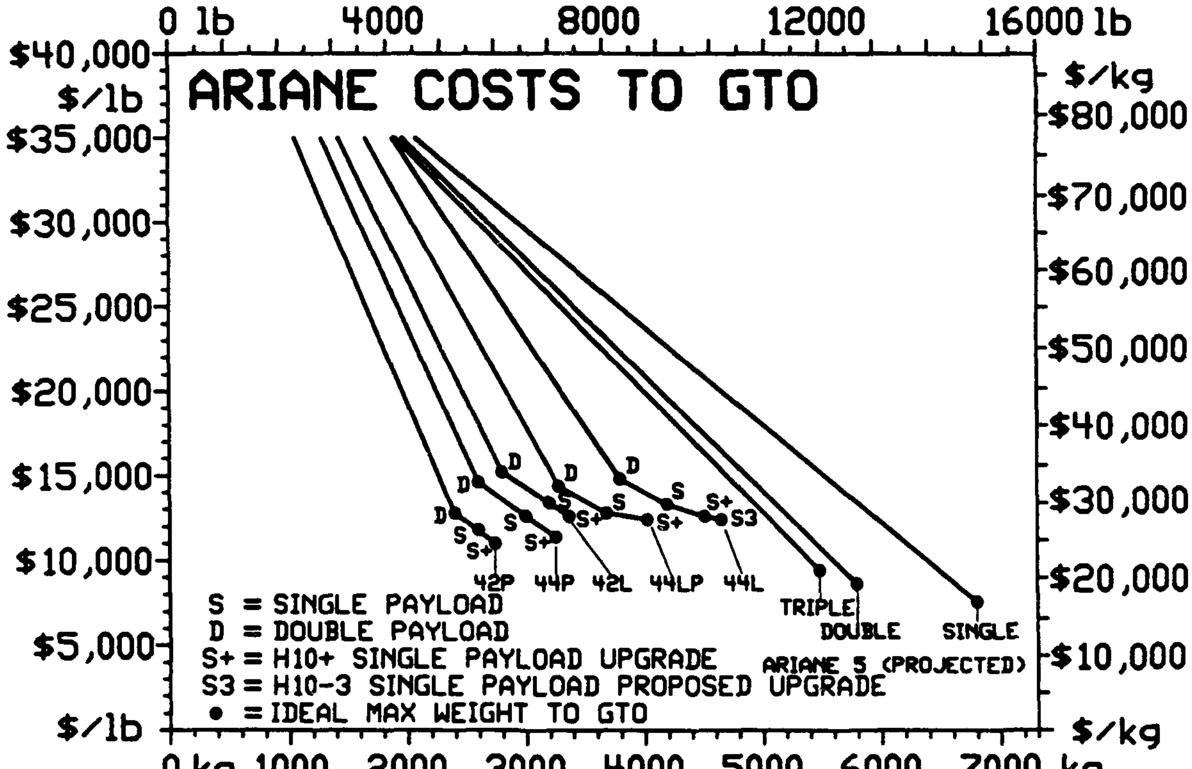

FIGURE 3-1. ARIANE COSTS TO GTO

payload costs will be somewhat higher ($8,500 per pound) along with a reduced payload capacity (1,000 lb), because of the extra hardware required to stack the satellites under one fairing.

Ariane 42P. The Ariane 42P, with two solid propellent strap-on boosters, is the smallest configuration, and had flown three successful flights to GTO by the end of 1992 (Appendix B-15). One of the flights was configured for a dual payload and the other two as single payloads (Figure 3-2). The double payload on Flight V-40, was very well matched to the weight capacity of the Ariane 42P. The other two flights used the extended upper stage modification, H10+, in order to avoid having to use the larger, more expensive, Ariane 44P.

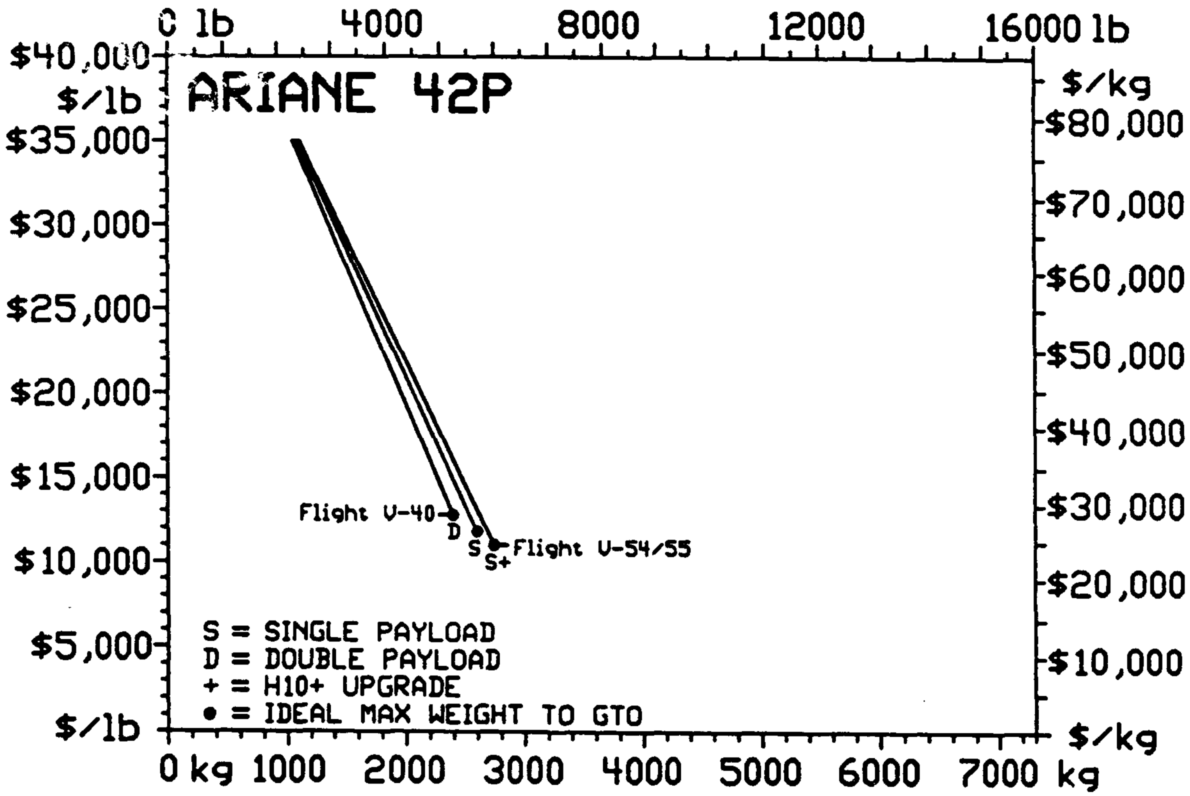

FIGURE 3-2. ARIANE 42P FLIGHTS TO GTO

Ariane 44P. The Ariane 44P, with four solid propellent strap-on boosters, is one step up from the 42P configuration, and has orbited two Canadian 2932 kg (6465 lb) satellites into GTO (Figure 3-3 and Appendix B-13). These two payloads reached 97% of the payload capacity. Estimated cost per pound was $12,993.

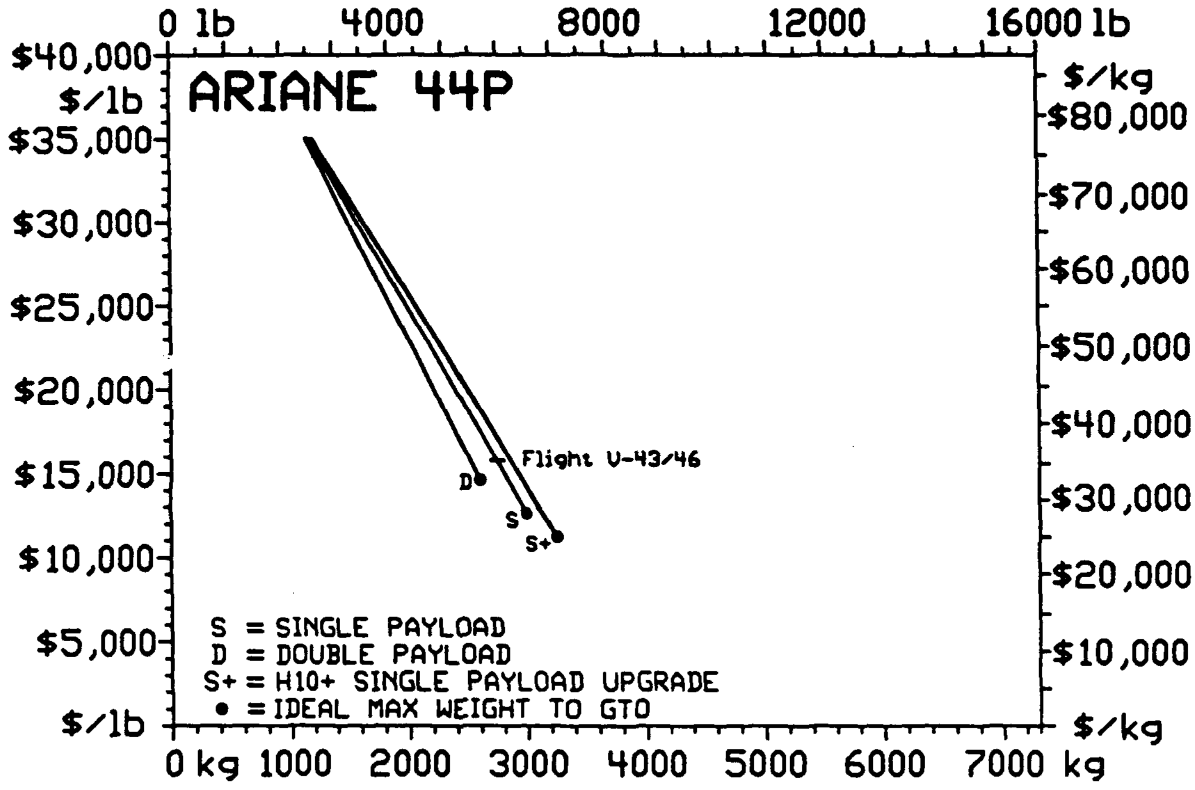

FIGURE 3-3. ARIANE 44P FLIGHTS TO GTO

Ariane 42L. The Ariane 42L, with two liquid propellent strap-on boosters, is the middle configuration, and has flown one successful dual payload to GTO in 1993 (Figure 3-4 and Appendix B-11). This flight illustrated how Ariane was able to match a large payload of 2790 kg (6152 lbs), with a small payload of only 151 kg (333 lbs), and still obtain 99% of the maximum payload capacity of the Ariane 42L.

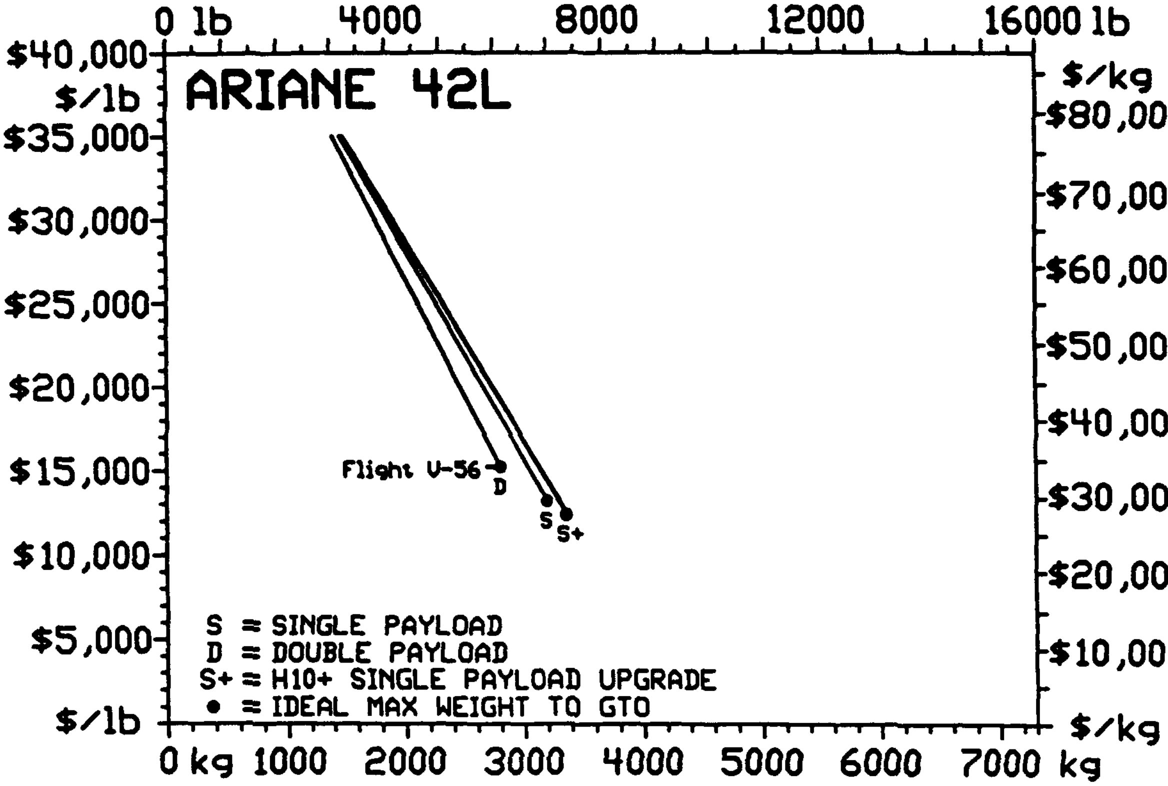

FIGURE 3-4. ARIANE 42L FLIGHTS TO GTO

Ariane 44LP. The Ariane 44LP, with two solid and two liquid strap-on boosters, is the second most powerful configuration, and has flown seven successful flights to GTO (Appendix B-7). Every one of the flights carried dual payloads and averaged 98% of the maximum rated payload weight. The exception, with only a 58% payload, was the first flight of the Ariane 4 in 1988 (Flight V-22), which carried three satellites to GTO, two commercial communications, and one small amateur radio satellite. Even though the flight was light, the payload customer obtained a considerably lower rate per pound than offered on subsequent flights, for promotional reasons. Charges per pound averaged about $15,300.

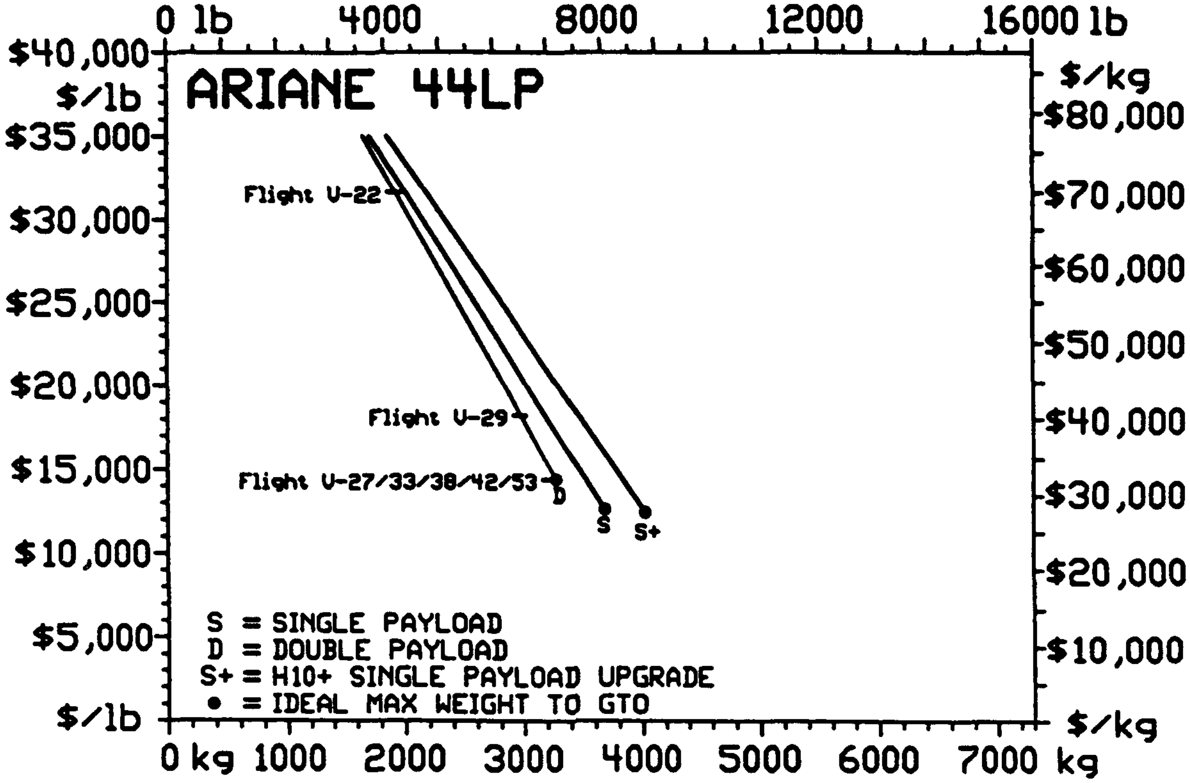

FIGURE 3-5. ARIANE 44LP FLIGHTS TO GTO

Ariane 44L. The Ariane 44L, with four liquid strap-on boosters, is the heaviest lifter of the Ariane family. It has flown eleven successful flights and had one failure through 1992 (Appendix B-2). Eight of the eleven flights carried dual payloads to GTO and averaged 96% of the maximum rated payload weight (Figure 3-6). Dual costs averaged $15,260. The exception, with only 86% of the rated weight, was the first flight of the Ariane 44L with the extended stage 3, the H10+ modification. Three of the eleven flights were large Intelsat 4600 kg (10143 lb) satellites that exceeded the rated payload capacity to orbit. Single payload costs averaged $12,324 per pound.

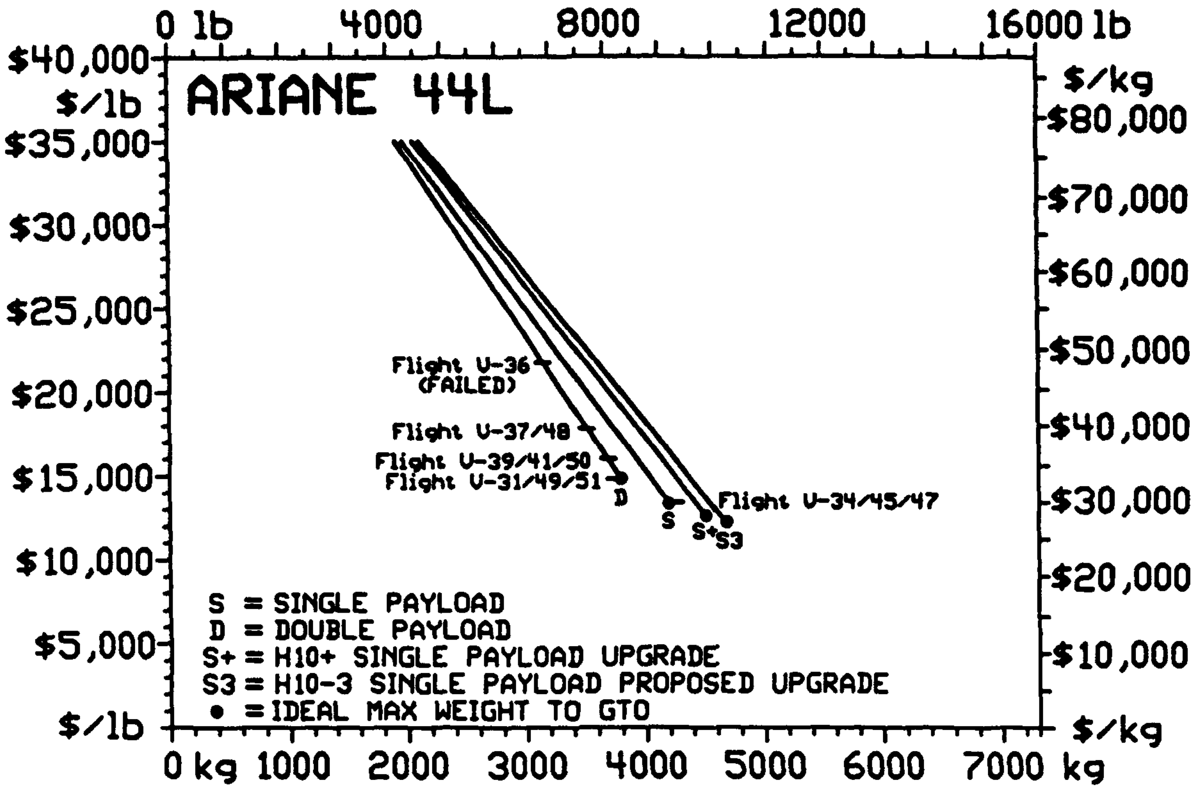

FIGURE 3-6. ARIANE 44L FLIGHTS TO GTO

Ariane Summary. Flights have averaged 98.6% of the maximum rated payload for the Ariane 4 since 1988. Because many of the payloads exceeded Ariane's rated maximums (some by as much as 10%), the average was recalculated, using 109.5% as the maximum load, and the new adjusted average became 89.8%. Nevertheless, Ariane costs per pound averaged considerably less than any other launch vehicle family. The five different launch configurations, the H10+ lengthened stage 3 option, and the multiple launch capability, makes Ariane the most flexible, and cost effective space launch vehicle in the world today. If Ariane 5 meets Arianespace expectations, they may continue to dominate the world's commercial satellite launch market for at least another decade.

Atlas GEO Launch Costs

The Atlas space launch vehicle has been in continuous production for forty years. General Dynamics first developed it as an ICBM in 1959. Many of the original Atlas ICBM launch vehicles, when deactivated, were converted to non-weapon payload carriers. Over 500 types of Atlas space launch vehicles have flown up to 1993.[7]

Atlas 1 and 2. The Atlas family has been divided into two basic models, the Atlas 1 and 2. A summary of the rated payload capacities and the costs per pound are shown in Figure 3-7. The Atlas 1 began as an 18 space launch vehicle investment

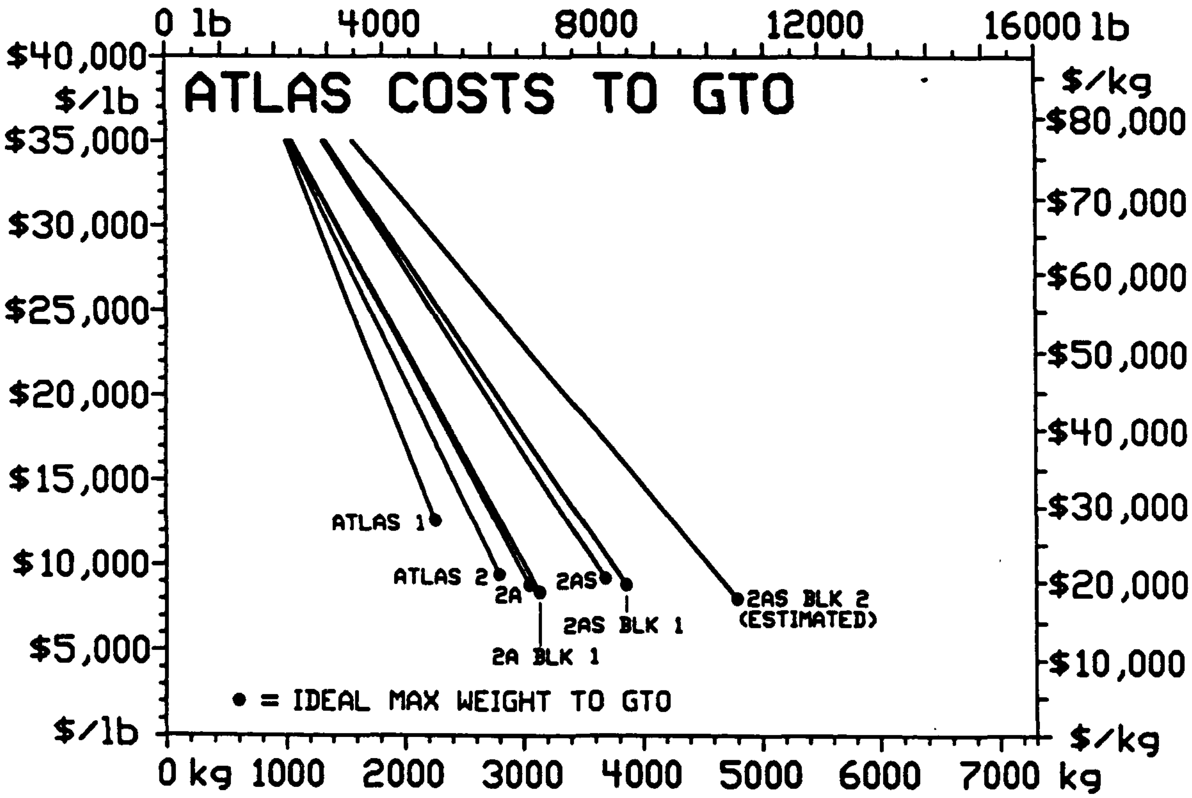

FIGURE 3-7. ATLAS COSTS TO GTO

that was increased to 62 by 1987. The Atlas 1 has two fairing options, medium and large, and a rated payload capacity of 2375 kg (5237 lb) for the medium fairing, and 2255 kg (4972 lb) with the large fairing. The Atlas 1 had a cost per pound rate to GTO of $12,030 with the medium fairing, and $12,671 with the large fairing, if the maximum rated capacity was utilized. The payload capacity of the Atlas 1 was slightly less than the smallest configuration of Ariane 42P. Comparing these two costs with the nearest Ariane configuration 42P at $11,255 per pound, the Atlas costs were roughly 10% greater than Ariane (Appendix C).

The Atlas 2 is a stretched version of the original Atlas Centaur, and was selected by the U.S. Air Force as the space launch vehicle for the second generation DSCS military communications satellites. The lift capacity of the Atlas 2 was increased to 2910 kg (6505 lb) for the medium fairing, and 2810 kg (6196 lb) for the large fairing. The Atlas 2 had a cost per pound rate to GTO of $8,916 with the medium fairing, and $9,361 for the large fairing, if the maximum rated capacity were utilized. The payload capacity was greater than the Ariane 42P, but slightly less than the next Ariane configuration 44P. Comparing the Atlas 2, $8,916 and $9,361 (medium and large fairing), with the Ariane 42P/44P, $11,255 and $11,580, the Atlas 2 was capable of launching payloads into GTO at a significantly lower rate. A 20% savings could be achieved from the Atlas 2 when payloads utilized the maximum capacities.

The Atlas 1 has attempted three GTO launches up to 1993, with two failures, and the payloads averaged less than 50% of the rated lift capacity (Figure 3-8). The Atlas 2 has launched three successful payloads to GTO, and their payloads averaged 88% of the rated lift capacity.

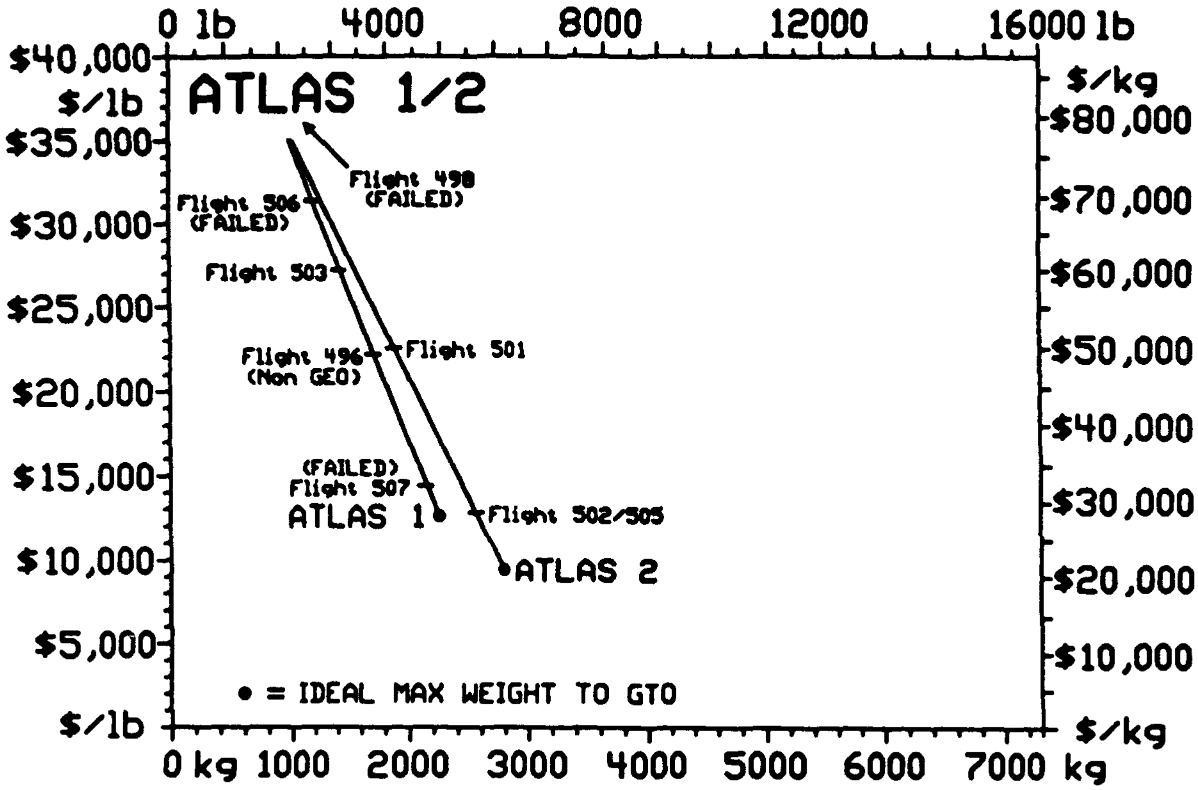

FIGURE 3-8. ATLAS 1/2 FLIGHTS TO GTO

Atlas 2A. The Atlas 2A is an enhanced version of the Atlas 2 and uses a different engine on the second stage. Performance was increased to 3040 kg (6703 lb) with the medium fairing, and 2900 kg (6395 lb) with the large fairing. The Atlas 2A has a cost per pound rate to GTO of $8,951 with the medium fairing, and $9,383 for the large fairing, if the maximum rated capacity is utilized. The payload capacity is similar to the Ariane 44P. Comparing the Atlas 2A, $8,951 and $9,383 (medium and large fairing), with the Ariane 44P, $11,580, the Atlas 2A is also capable of launching payloads into GTO at a significantly lower rate than Ariane (roughly a 20% savings), utilizing maximum payload capacities.

Atlas 2A, Block 1. The Atlas 2A, Block 1, has an upgraded engine which increases the performance to 3160 kg (6968 lb) with the medium fairing and 3045 kg (6714 lb) with the large fairing. The Atlas 2A, Block 1, has a cost per pound rate to GTO of $8,611 with the medium fairing, and $8,937 for the large fairing, if the maximum rated capacity is utilized. The payload capacity is similar to the Ariane 44P with the H10+ modification. However, the Atlas 2A, Block 1 can launch payloads into GTO at a significantly lower rate than Ariane (roughly a 25% savings) utilizing maximum payload capacities.

Atlas 2AS. The Atlas 2AS is a 2A with four solid propellent strap-on boosters which increases the performance to 3700 kg (8159 lb) with the medium fairing and 3560 kg (7850 lb) with the large fairing. The Atlas 2AS has a cost per pound rate to GTO of $9,192 with the medium fairing and $9,554 for the large fairing, if the maximum rated capacity is utilized. The payload capacity is similar to the second most powerful Ariane, the 44LP, but it too can launch payloads into GTO at a significantly lower rate than Ariane (roughly a 25% savings) utilizing the maximum payload capacities.

Atlas 2AS, Block 1. The Atlas 2AS, Block 1, is a 2AS with an upgraded engine that increases the performance to 3830 kg (8445 lb) with the medium fairing and 3700 kg (8159 lb) with the large fairing. The Atlas 2AS, Block 1, has a cost per pound rate to GTO of $8,881 with the medium fairing, and $9,192 for the medium fairing, if the maximum rated capacity is utilized. The payload capacity is similar to the Ariane 44LP with the H10+ modification. Comparing once again, the Atlas 2AS is roughly 25% more cost effective than its Ariane counterpart when launching payloads into GTO utilizing maximum payload capacities.

The first Atlas 2A was launched in June of 1992, and successfully placed a satellite into GTO which used 97.8% of the available payload limit and cost the customer about $9,595 per pound. The first Atlas 2AS was launched in December of 1993, and carried a payload that used 84% of the Atlas maximum rated payload and cost about $10,971 per pound (Figure 3-9).

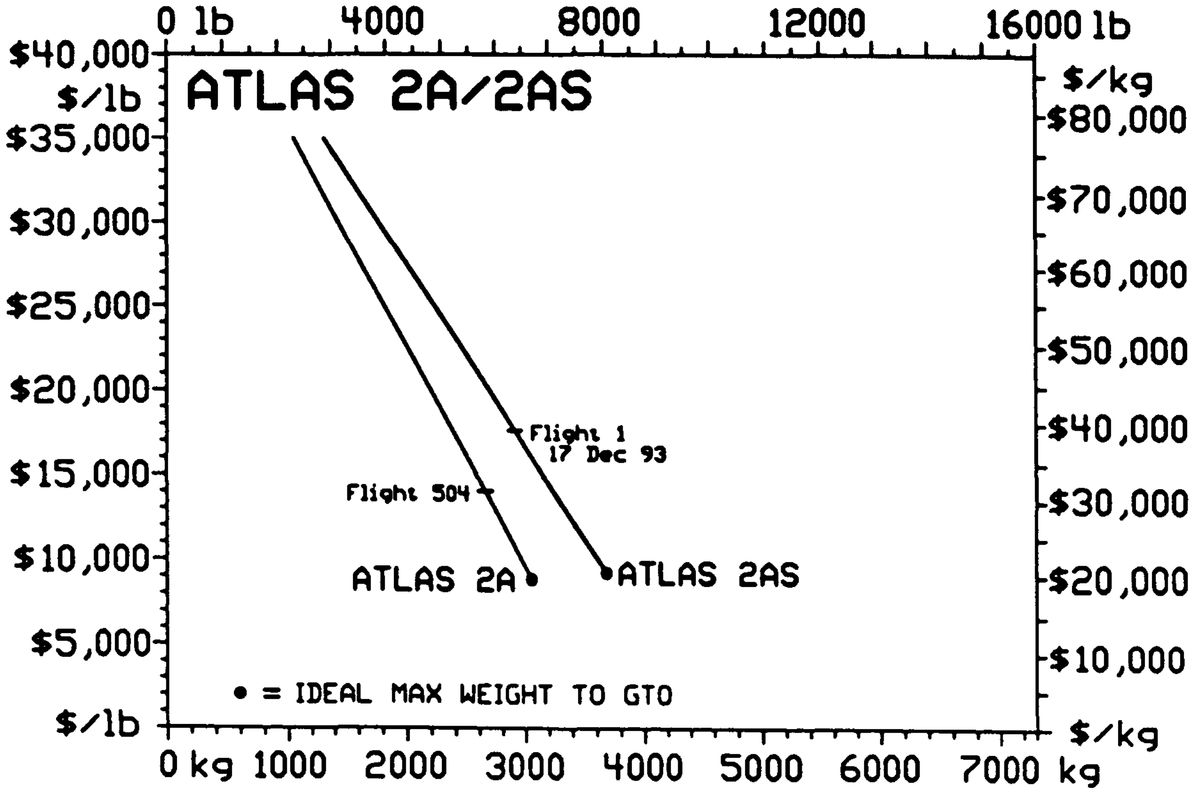

FIGURE 3-9. ATLAS 2A/2AS FLIGHTS TO GTO

Atlas 2AS Upgrades. The upgraded Atlas 2AS is in the planning stages, and could increase GTO payload capacity to 4540-4990 kg (10011-11003 lb). The projected upgrades may stretch the fairing, second stage, and the strap-on solid boosters, to achieve additional payload capacity. If the costs for an upgraded Atlas 2AS can be kept down, then the rates to GTO may be as low as $6,816.

Atlas Summary. The Atlas 2 family (2A, 2A Block 1, 2AS, and 2AS Block 1) of space launch vehicles, offers the lowest prices of any western world manufactured GTO carrier. The Atlas 2A, Block 1, has the lowest rate of the family at $8,611 per pound, assuming it carries a maximum load. If Atlas offered the best rate per pound, why didn't they have a larger share of the commercial satellite launch market? The low cost Atlas rates were only effective for flights carrying a full load. Most commercial satellite payloads fell short of filling the Atlas and, hence, the actual costs per pound were considerably higher. Atlas payloads averaged only 76% of the maximum rated payload limit, which is typical for a space launch vehicle that does not have multiple payload options that allows matching of payloads to bring the averages up. The Atlas 2 was tailor-made to launch military Navy UHF follow-on satellites (UFO), and thus they realized the lowest rates because they took advantage of the maximum payload capacity of the Atlas 2. Currently scheduled commercial launches continue to fall short of the maximum allowed weight. Even so, with the Atlas 2 family costs per pound about 25% less than Ariane, a satellite weighing only 80% of the maximum allowed payload can be flown for the same price as an Ariane with a 100% payload.

Chinese GEO Launch Costs

The Chinese launched their first successful GEO satellite in April of 1984, just three months after the failure of their first attempt. The CZ-3, (CZ = Chang Zheng = Long March) carried China's first communications test satellite and their first commercial satellite to GTO. The CZ-3 cost per pound is $12,860 to GTO if the maximum payload capacity of 1340 kg (2955 lb) is utilized (Appendix D and Figure 3-10). China's most powerful vehicle, the CZ-2E is able to carry 3140 kg (6924 lbs) to GTO for $6,354 per pound. The lower CZ-2E rates, however, may not represent actual costs because of government subsidies.[8]

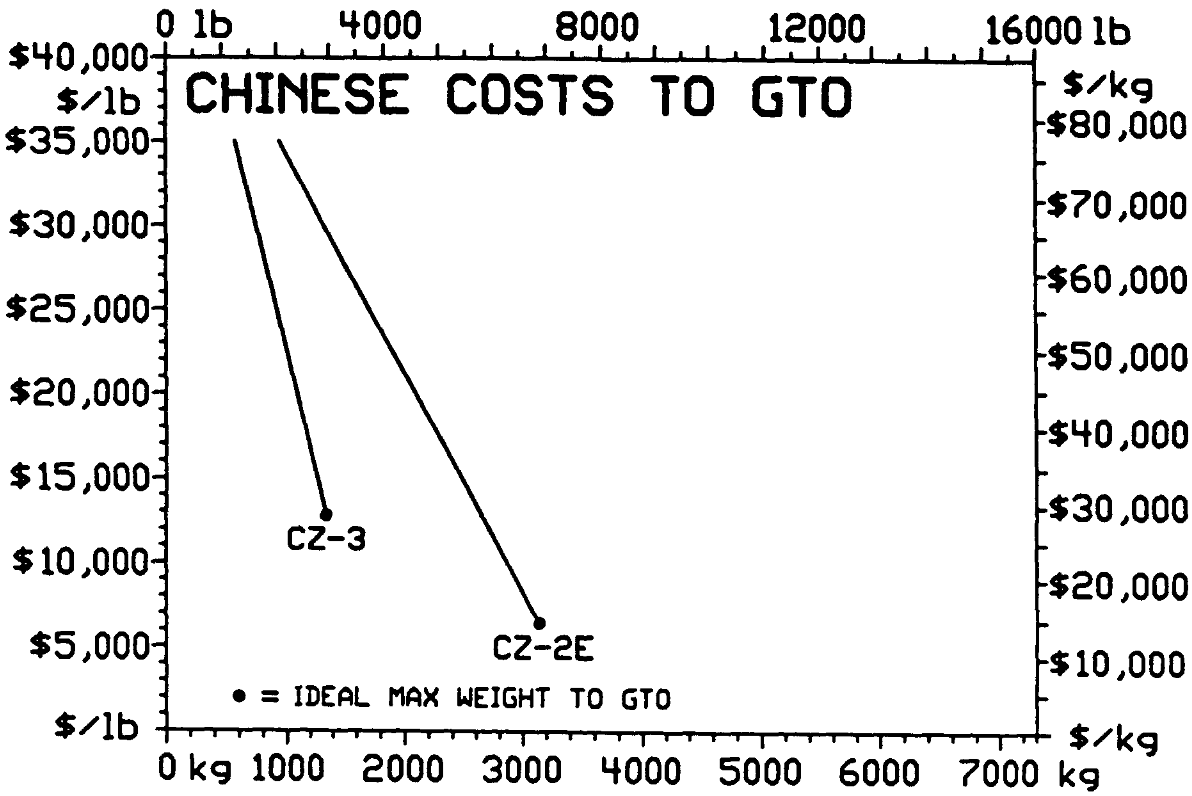

FIGURE 3-10. CHINESE COSTS TO GTO

The smaller CZ-3 attempted eight flights to GTO with two failures. One of the six successful payloads was a commercial satellite. Asiasat 1 consumed 92.8% of the maximum payload capacity and cost the customer about $13,489 per pound. The average payload utilized 78% of the maximum rated payload capacity for the CZ-3 (Figure 3-11).

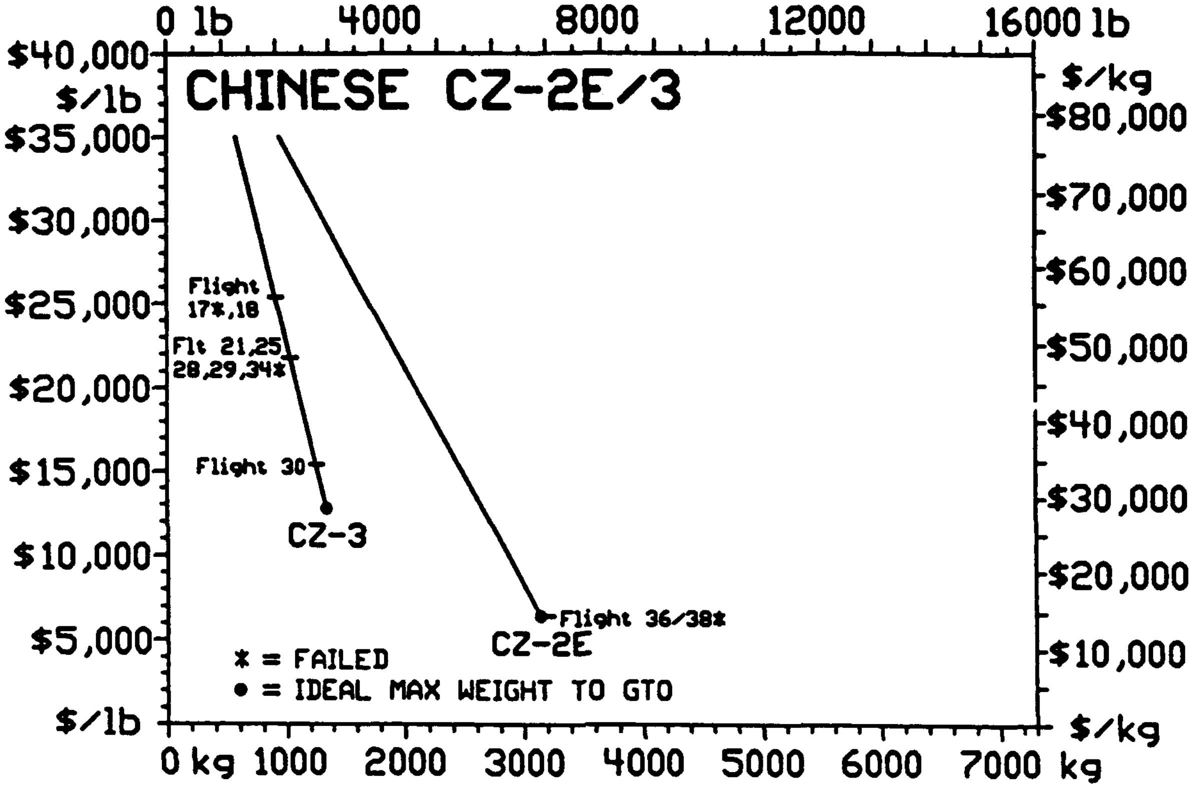

FIGURE 3-11. CHINESE CZ-3/CZ-2E FLIGHTS TO GTO

The larger CZ-2E has made only three flights with one failure. The first flight was a successful test of the basic vehicle using a dummy satellite and the other two carried commercial satellites, one of which did not make it to orbit. Both commercial satellites utilized 100% of the payload capacity for the CZ-2E and a rate of $6,306 per pound was charged for the flights.

Chinese CZ-2E/3 Summary. The Chinese gave Australia's Optus satellite owners the lowest rates ever offered for launching commercial satellites. A promotional price of $15 million each, $6,306 per pound for two 3164 kg (6977 lb) payloads to GTO. One was successfully launched in August 1992 and the second failed to reach orbit. In 1988, the U.S. limited the export of U.S. manufactured satellites to nine to the end of 1994 because of the suspected unfair pricing.[9] In spite of the low rates per pound, China has only launched two commercial satellites, one small 1244 kg (2743 lb) satellite on the CZ-3 in 1990, and one larger 3164 kg (6977 lb) satellite on the CZ-2E in 1992. A number of factors may explain why the Chinese low cost flights are not more popular: (1) the CZ-2E has only flown three times, (2) one of the three flights was a failure, (3) less than two flights per year were flown, and (4) the U.S. satellite export restriction. It will take about ten successful flights of the CZ-2E before it is considered a mature and reliable space launch vehicle. With only two flights a year, it will take a number of years before the launch capability of the CZ-2E can be proven.[10]

Delta GEO Launch Costs

The McDonnell Douglas manufactured Delta has been in production since 1959, and has launched over 200 satellites into orbit. There have been a number of older Delta models and all of them have been relatively small launchers. About a third of its flights have been GEO commercial satellites. The older Delta II 6925 was more expensive per pound and carried a smaller payload than the newer Delta II 7925 (Figure 3-12). The Delta II 6925 military cost per pound was $13,475 and the commercial version was $18,176. The commercial version of the Delta II 6925 was one of the more expensive space launch vehicles in the U.S. inventory. The smallest Ariane 4 can carry considerably more weight into orbit than the Delta II 7925.

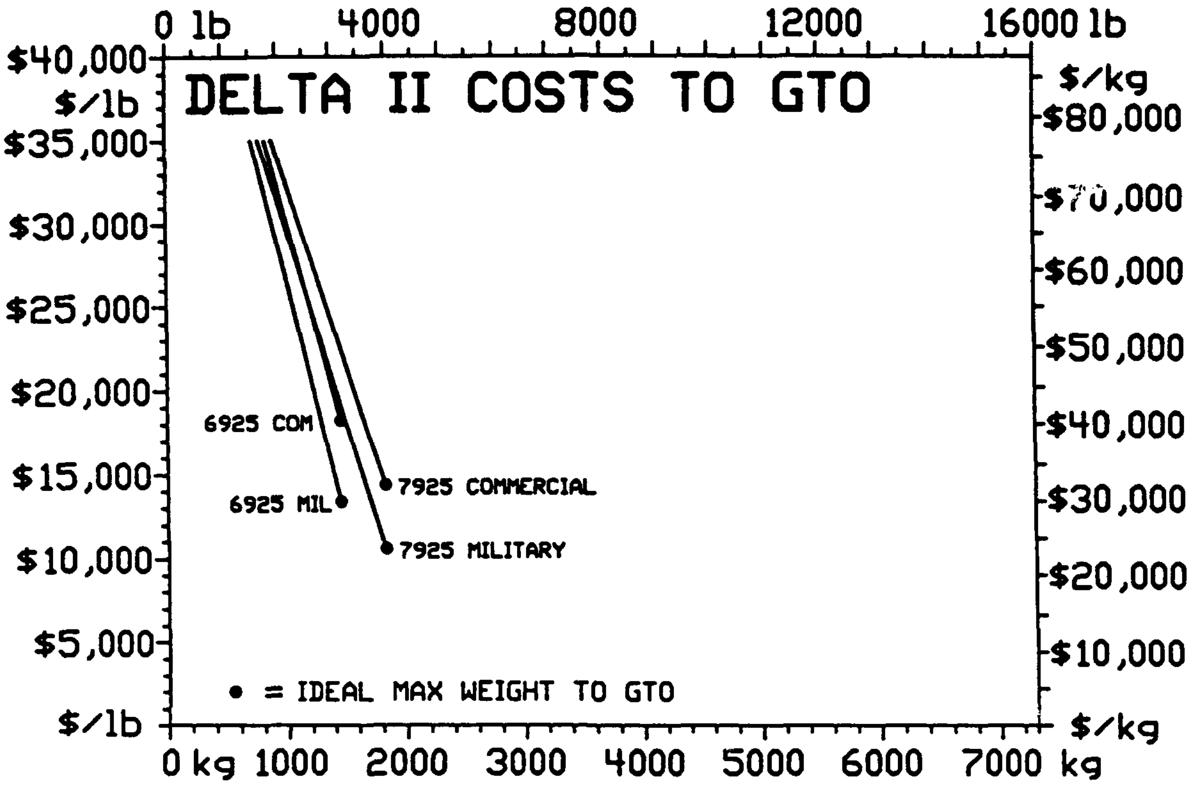

FIGURE 3-12. DELTA II COSTS TO GTO

China's smaller CZ-3 has a similar payload capacity and the rates are also similar. The current McDonnell Douglas configuration is the Delta II 7925, which is capable of launching 1819 kg (4011 lb) to GTO, for a military cost of $10,721, and a commercial cost of $14,460 per pound (Figure 3-12).

Delta II 6925. The Delta II 6925 has made 17 successful flights during its lifetime, without any failures (Figure 3-13). Only four launches carried commercial payloads to GTO. Nine of the flights took military satellites to an orbit lower than GEO, and the remaining four were low-Earth orbit flights. The Delta II 6925 was designed to carry military payloads and commercial flights were secondary. All nine military flights utilized 100% of the payload capacity and cost $11,697 per pound. The costs per pound were less than the GTO costs because the Delta II 6925 was capable of carrying additional weight to the lower altitude. The four commercial GEO satellite weights utilized an average of 90.9% of the maximum payload limit for the Delta II 6925.

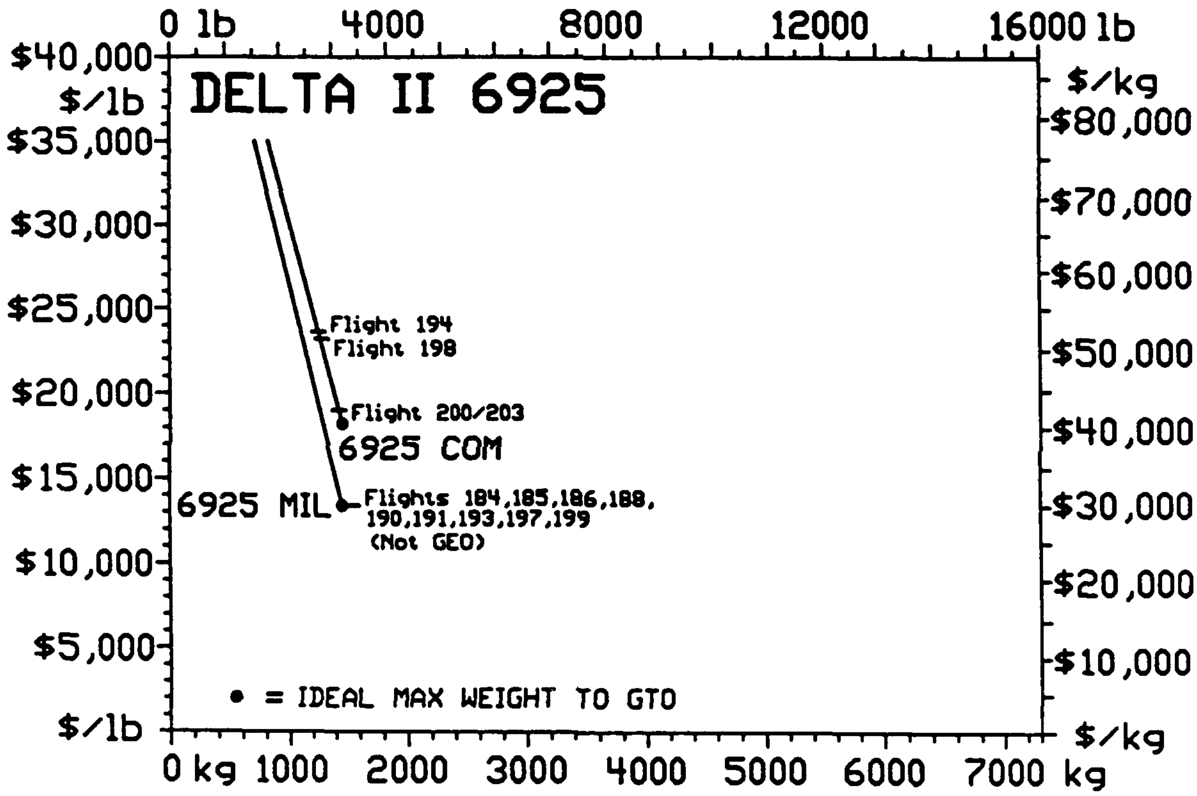

FIGURE 3-13. DELTA II 6925 FLIGHTS TO GTO

<u>Delta II 7925</u>. The Delta II 7925 made 16 successful flights without any failures. Six of the launches carried commercial payloads to GTO and the remaining ten took military satellites to lower orbits. The Delta II 7925 was also designed primarily to carry military payloads, whereas, the commercial flights were secondary.

All nine military flights utilized 100% of the payload capacity, for a cost per pound of $10,366, to an orbit below GEO. The costs per pound are less than the GTO costs, because the Delta II 7925, like the 6925, is capable of carrying additional weight to the lower altitude. The six commercial GEO satellite weights utilized an average of only 74.2% of the maximum payload limit for the Delta II 7925 (Figure 3-14).

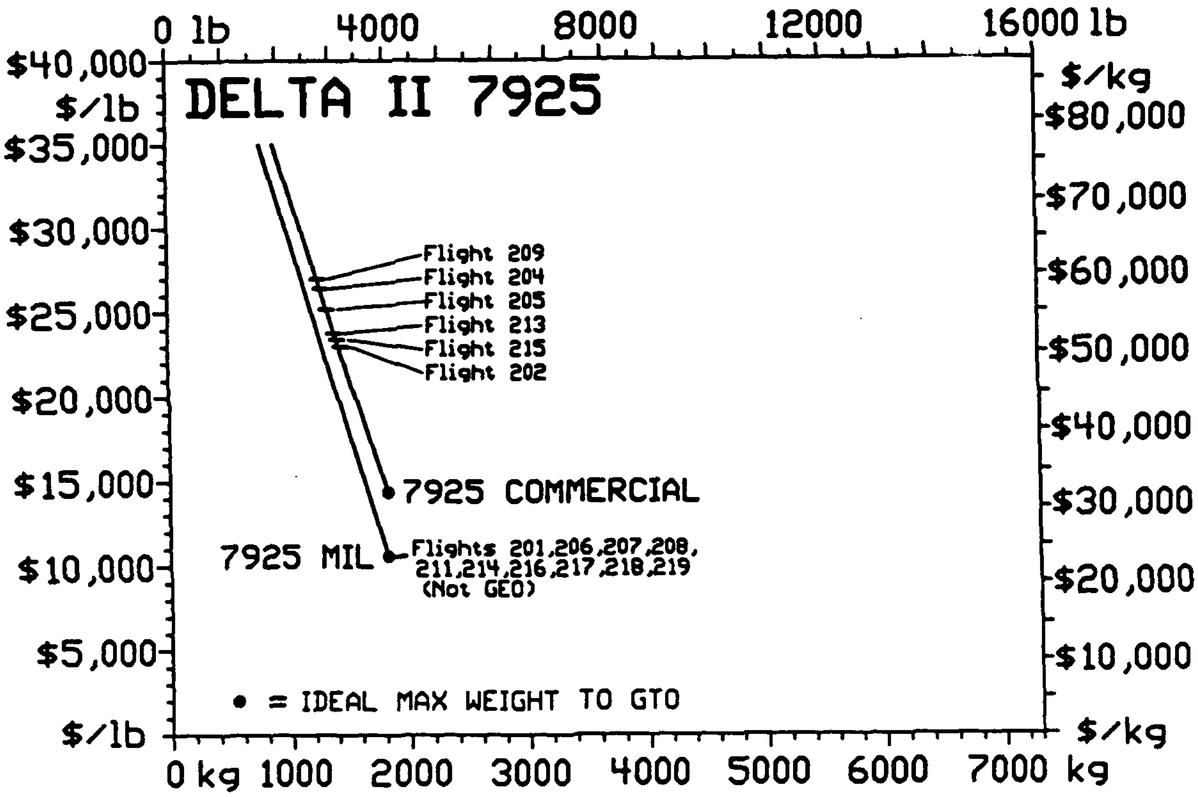

FIGURE 3-14. DELTA II 7925 FLIGHTS TO GTO

Delta II Summary. The $10,721 cost per pound rate for the military version of the current Delta II 7925, is nearly 30% less than the $15,000 average rate for a similar flight on Ariane. However, the Delta II 7925 commercial rate of $14,460 is nearly the same as Ariane. The Delta II 7925 strap-on booster upgrade has allowed increased payload capacity with minimal overall cost increases from the original Delta 6925. The Delta II 7925 military and commercial rates have been 20% less than the previous Delta II 6925. The military cost per pound rates have dropped from $13,475 to $10,721 and the commercial rates have dropped from $18,176 to $14,460 per pound.

Japanese H1/H2 GEO Launch Costs

The Japanese have been developing space launch vehicles since 1975. Their first launch vehicle, the N1, was modeled after the Delta, under a 1970 license agreement which restricted them from launching third party commercial satellites. Over the years, the Japanese have been released from the original restrictions.[11] The H2 is the first completely Japanese built space launch vehicle.[12]

H1. The H1 Delta size has flown nine successful missions, and six of those have taken communications satellites to GTO. The H1 was retired with a 100% success rate having only flown Japanese satellites. The $23,495 cost per pound, however, never allowed the H1 to be competitive. It did provide them the necessary experience to develop the current H2 (Figure 3-15 and Appendix F).

H2. The H2 was designed to carry 4000 kg (8820 lb) to GTO for $6,803 per pound but has not yet proven a reliable space launch vehicle. Low launch costs have not yet been achieved with actual costs to GTO about $17,000 per pound, which is non-competitive with other space launch vehicles. Will the Japanese attempt to subsidize the H2 to make it more competitive? If they do, the subsidies may not come from the government but from Japanese businesses. Their R&D expenditures have been about double U.S. R&D. Another unresolved drawback is the political and environmental limitation of four flights per year due to concerns of local fishing industries.[13]

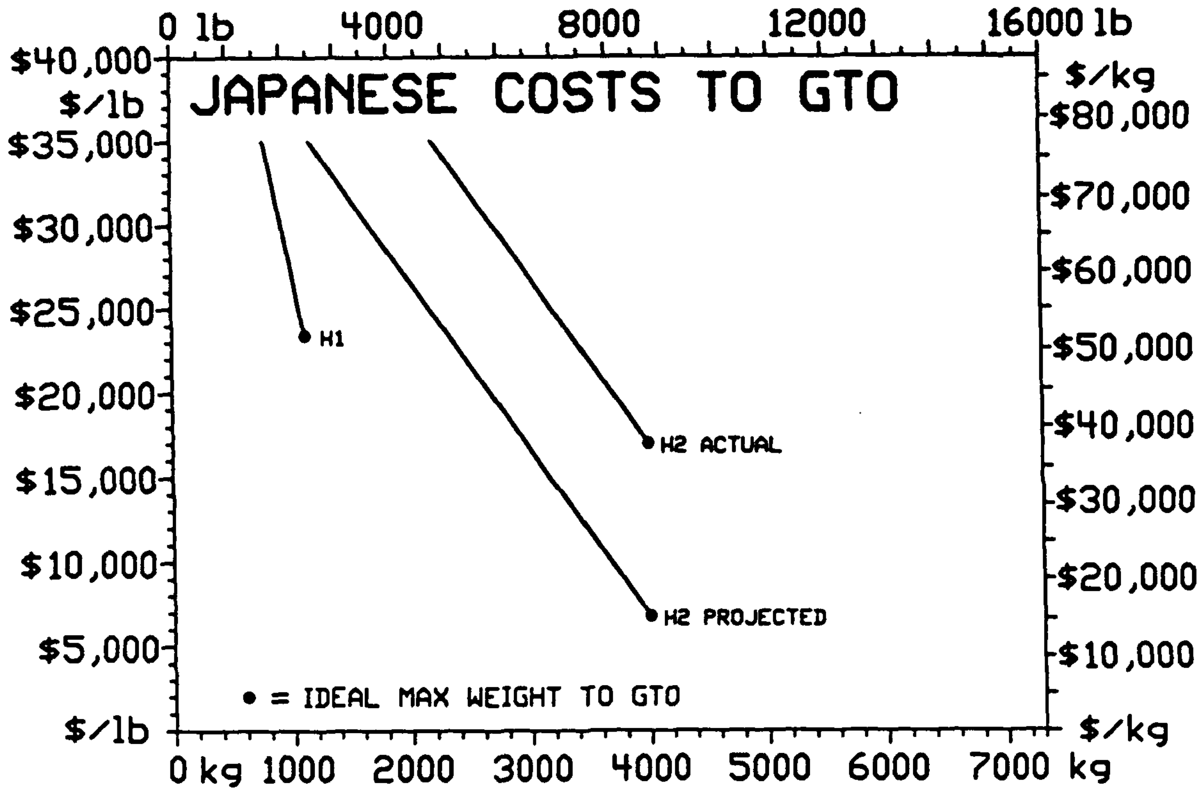

FIGURE 3-15. JAPANESE H1/H2 COSTS TO GTO

Six of the nine flights of the H1 have been to GTO. The payloads averaged 95% of the maximum 1100 kg (2426 lb) and costs averaged $25,494 per pound. The recent promotional flight of the H2 carried a 2395 kg (5280 lb) payload to GTO utilizing only 60% of the payload capacity for about $28,400 per pound (Figure 3-16).

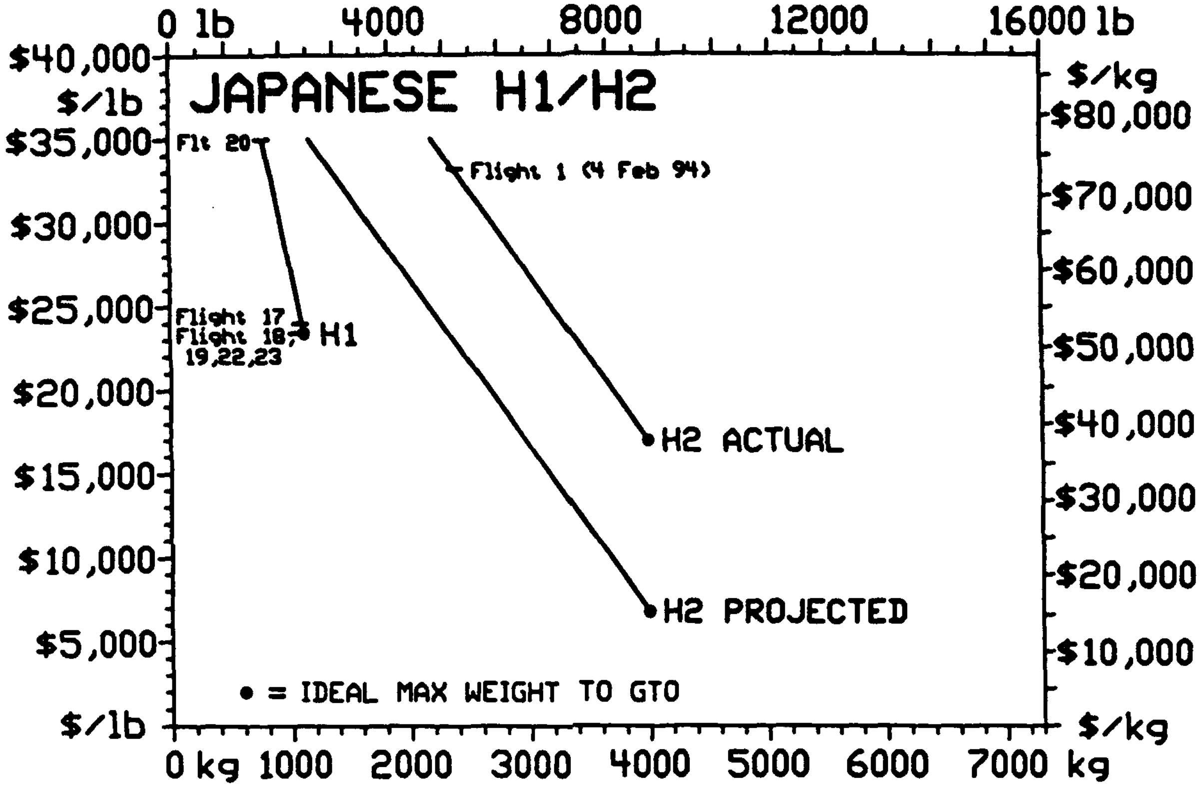

FIGURE 3-16. JAPANESE H1/H2 FLIGHTS TO GTO

Japanese H1/H2 Summary. The cost per pound rates for both the H1 and the H2 have not been low enough to be competitive. The Japanese must accomplish three things to become competitive: (1) reduce costs, (2) increase the number of flights per year, and (3) establish a history of success.

Russian Proton GTO Launch Costs

Russia has more experience at launching spacecraft than any other country in the world. Russia has launched over 2400, compared to the 1000 U.S. space launch vehicles since 1957.[14] Only 90 of the 2400 payloads have gone to GEO because Russia has extensively used molniya elliptical orbits for communications. The molniya orbit worked well for communications satellites intended to provide coverage near the poles where GEO satellites are out of range. The northern latitudes of Russia made molniya orbits as practical as GEO satellite communications.

All 90 of Russia's GEO launches have flown on the Proton space launch vehicle even though other models have been rated to GEO. The Russians have offered the Proton with its 4600 kg (10143 lb) payload capacity for only $3,549 per pound, assuming a maximum payload (Figure 3-17 and Appendix G). The Inmarsat 3-F4 has been scheduled to be launched to GTO aboard a Proton in 1995 but will cost about $8,250 per pound because the Inmarsat's 1980 kg (4366 lb) utilizes only 43% of the maximum payload capacity. Even so, the $8,250 per pound rate was

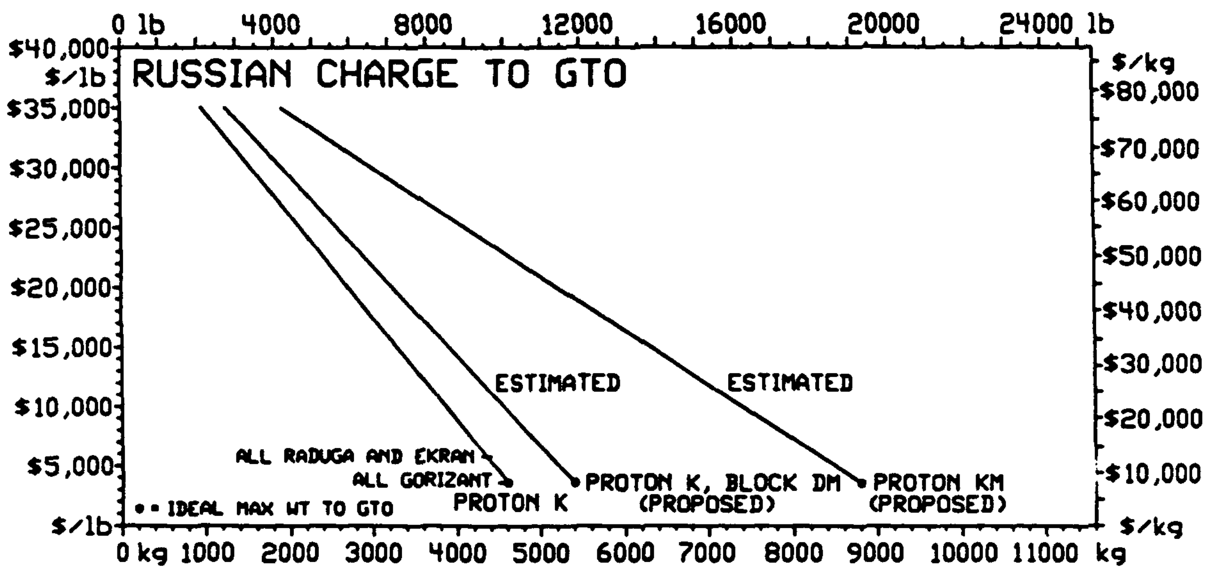

FIGURE 3-17. RUSSIAN CHARGES TO GTO

considerably less than the best price that Ariane, or any other space launch company, could offer. Inmarsat's 1980 kg satellite weight does not come near utilizing the maximum payload of the Proton or any other launch vehicle. The Proton rate was so low that the total cost was still considerably less than any other space launch vehicle. The next least expensive flight would have been the $15,000 per pound rate aboard a multiple payload Ariane, assuming Ariane could find a matching smaller satellite, to bring the total payload weight up to the maximum of any of its configurations.

Russian Proton Summary. The Proton is similar, in payload capacity, to the largest Ariane 44L configuration. The Russians have been considering enhancements to increase the payload capability to as much as 8800 kg (19404 lb) to keep up with the anticipated growth of commercial and Russian satellites. Russia has been promising large payload capacities with low rates to both low-Earth and GTO, using the Energia. However, the Energia has flown only two LEO missions, one in 1987 and the other in 1988.[15] U.S. trade restrictions have severely hindered Russia's progress toward commercialization, but loopholes are being sought. The biggest break for the Russians may have begun with the signing of a 20-year contract with Australia for commercial launch services from Papua New Guinea.[16] The Russian Proton would be able to take a much heavier 5612 kg (12374 lb) payload to GTO because of the equatorial launch advantage.

Shuttle Launch Costs to GTO

The Shuttle space launch system has been the only U.S. government (NASA) owned and operated geostationary capable launch platform. NASA has launched 63

Shuttles between 1981 and 1992, with one notable failure, Flight #25. The Shuttle has delivered 23 commercial and 8 military satellites to GEO. Three political decisions confused and impacted the U.S. space launch program. One, a 1979 decision to fly all military payloads on the Shuttle, ended procurement of U.S. military expendable launch vehicles by 1984.[17] Then the Shuttle Challenger accident in 1986 led to an immediate reinstatement of expendable launch vehicles. Finally in 1986, President Reagan decided to prohibit commercial payloads from being carried aboard the Shuttle.[18] These three decisions convinced the manufacturers of the Atlas, Delta, and Titan to start their own commercial launch companies independent of unpredictable government space policy.

The cost to send a Shuttle to LEO averaged $330 million and only a small percentage of that was ever returned by launching satellites bound for geostationary orbit. If the cargo bay could be filled with a 24,950 kg (55,015 lb) payload, then the cost per pound to LEO would only be $2,548. If the Shuttle were to carry four Delta-size payloads, a $12,000 per pound rate would pay for the flight (Figure 3-18 and Appendix H). This was the argument that NASA used to secure the first policy change. There were not enough available satellites to fill up the Shuttle for a one-a-month launch. Besides that, the only low cost, medium payload, upper stage rocket, the Atlas Centaur, was banned from the cargo bay for safety concerns, and the replacement Inertial Upper Stage (IUS) was entirely too expensive.

Shuttle Summary. The NASA Shuttle took a large number of commercial payloads to LEO, at comparable launch prices to Ariane, during the middle eighties. However, the Shuttle has been subsidized heavily by government, mainly because it has been a man-rated system. Astronauts consume valuable cargo space and require

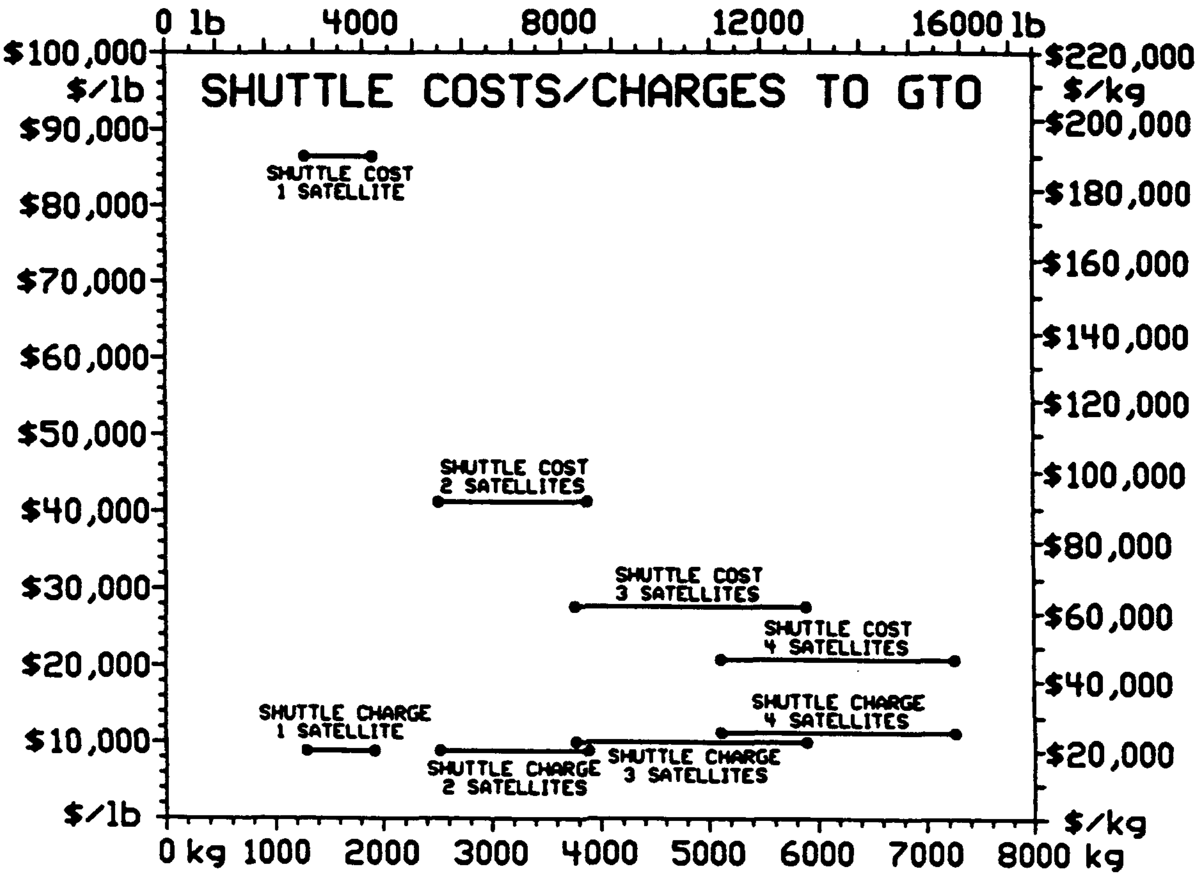

FIGURE 3-18. SHUTTLE COSTS/CHARGES TO GTO

more reliable vehicles because of safety concerns. The Shuttle only flew to LEO, which meant that an additional costly upper stage was required to reach GTO. The military IUS upper stage has ended up costing $75 million each for fifteen units making the Shuttle no longer a viable commercial satellite carrier. Subsidizing the Shuttle to make it competitive is no longer considered an acceptable practice for fair trade.

Taurus/Pegasus Launch Costs

The U.S. Taurus and Pegasus space launch vehicles have been manufactured by Orbital Sciences Corporation, and Hercules, for the launch of small payloads to LEO and GTO. The payload range for both vehicles is significantly less than the Delta's. The smaller Pegasus was designed to be drop-launched from an airplane for quick access to space for small payloads. The larger and later Taurus was basically the Pegasus with an additional stage added to the bottom to substitute for the airplane lift.

Pegasus. The Pegasus is the smallest remaining U.S. launch vehicle. Payload capacity to GTO has been rated at 165 kg (364 lb), but it has to deliver a satellite to GTO. The cost per pound rate to GTO is expected to be about $32,967, which is too high to be competitive for GTO flights (Figure 3-19 and Appendix I).

Taurus. To reduce the cost per pound, the Pegasus was upgraded, by replacing the airplane lift with a more efficient solid rocket motor. The Taurus flew its maiden flight in March 1994 and successfully carried two satellites to LEO. The payload capacity to GTO was increased by over 200% to that of the Pegasus. Three configurations of the Taurus have been designed with the following GTO payload capabilities: (1) Taurus 120, basic configuration (514 kg/1133 lb), (2) Taurus 120XL, an extended version of the 120 (595 kg/1312 lb), and (3) the Taurus 120XLS, a 120XL with two solid strap-on boosters (736 kg/1623 lb). Cost per pound estimates have decreased significantly from the Pegasus to $13,815 per pound for the Taurus 120, $11,930 for the 120XL, and $9,644 for the 120XLS.[19]

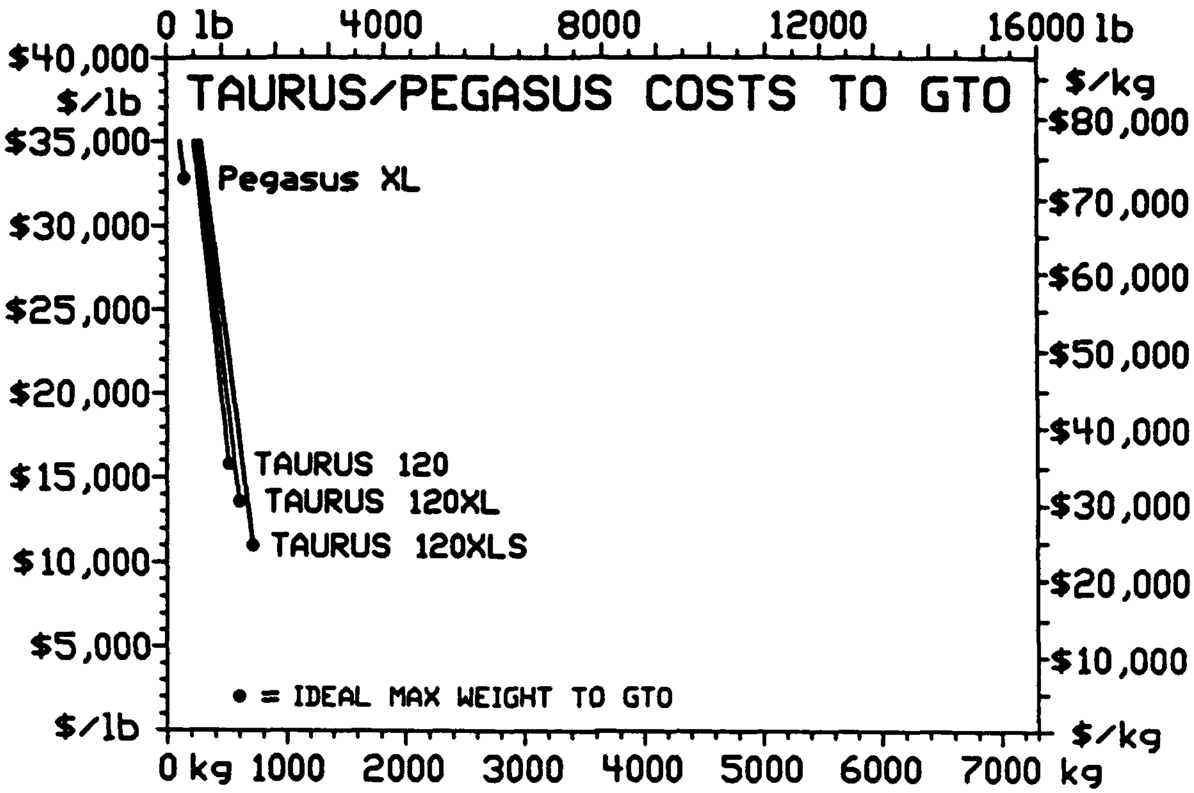

FIGURE 3-19. TAURUS COSTS TO GTO

Taurus and Pegasus Summary. Because of its small payload capability to LEO, the Pegasus seems to have found a niche not covered by any other launch vehicle. Even though the rates for the Pegasus are high for both LEO and GTO launches, customers have been signing up for LEO launches. No GTO launches have been procured because Ariane can deliver these smaller payloads for about half the cost. The Taurus, which is considerably less expensive and can deliver 736 kg (1623 lb) payloads to GTO, for $11,091 per pound (a 25% savings over the dual payload $15,000 per pound Ariane), is conservatively priced but few small (Taurus-size) GEO bound commercial satellites are being built.

Titan Launch Costs

The Martin Marietta Titan 3 has been primarily used for launching U.S. government and military payloads since 1964. A Titan 3A launched the world's first GEO satellite in 1965, from Cape Canaveral, Florida. The Titan family consists of four basic models: (1) the Titan 1 ICBM, (2) the Titan 2 ICBM, (3) the Titan 3 LEO and GEO satellite launch vehicle, and (4) the Titan 4 heavy lifter to LEO and GEO. Refurbished Titan 2 vehicles have been carrying small payloads to LEO with conversion costs approaching $40 million each. The Titan 3 has been the most popular of the Titan vehicles and has placed more than 150 government and military payloads into orbit or deep space.[20]

Titan 3. Titan launch vehicles were not used to launch commercial satellites until Martin Marietta formed a commercial division in 1986 with flights starting in 1989. The Titan 3 was designed to carry single or dual payloads, but the dual payload option has been very limited due to payload size and cost. The Titan 3 takes payloads to a circularized low-Earth orbit before proceeding on to GTO and GEO which means an additional two stages are required to take the payload to GTO. The Payload Assist Module (PAM) was designed to carry up to 1851 kg (4081 lb) to GTO, but has not able to handle the heavier, more common commercial payloads. A military contract provided the resources for the design and implementation of the larger capacity 4944 kg (10902 lb) Inertial Upper Stage (IUS) that ended up being too expensive for competitive commercial launches.[21] A newer, equally capable, commercial version Transfer Orbit Stage (TOS) was designed and flown in 1992, which helped reduce the cost per pound rates. The Titan 3 is capable of delivering dual payloads totaling 4000 kg (8820 lb) to GTO for about $13,832 per pound, or a single payload of 4944 kg (10902 lb) for $10,090 (Figure 3-20 and Appendix J).

Titan 4. The Titan 4 is the heaviest expendable launch vehicle in America. It was designed to replace the Shuttle that was going to carry low altitude payloads to polar orbit from Vandenberg AFB. Construction of the Vandenberg Shuttle launch facility was cancelled. The GEO launch option was added to the Titan 4 by using either an Atlas Centaur or a Boeing Inertial Upper Stage (IUS). Both of these upper stages, and their payloads, are first taken to LEO by the Titan 4. The Centaur upper stage has proven more cost effective than the IUS solid propellent upper stage because of its more efficient liquid hydrogen and oxygen engines.

The Titan 4 has four configurations for delivering payloads to GEO. The four configurations were made possible by offering two different upper stages (Atlas Centaur and Boeing IUS), and two different strap-on boosters (United Technologies Solid Rocket Motor (SRM) and Hercules Solid Rocket Motor Upgrade (SRMU). Both the Centaur and IUS were designed to take payloads directly to GEO instead of using the typical GTO delivery provided by other commercial space launch vehicles.

The smallest GEO Titan 4 configuration (IUS and SRM) is able to deliver 2364 kg (5212 lb) payloads directly to GEO for about $36,447 per pound. Cost per pound rates to GEO have been at least double the rates to GTO because about 50% of the weight of satellites in GTO are required for propellent to reach GEO. No other launcher, except the Russian Proton, has taken payloads directly to GEO. An equivalent GTO rate was estimated before comparisons to other GTO launch vehicles were made. The Titan 4 (IUS and SRM) would have an equivalent GTO payload capability of 4298 kg (9478 lb), with an estimated cost of $20,046 per pound; still too high to be competitive for commercial satellite launches. The cost per pound rates improve as payload capacity increases. The next configuration Titan (IUS and SRMU) has an estimated GTO payload capability of 6306 kg (11465 lb), and cost of $17,444 per pound. The Titan 4 (Centaur and SRM) has a GTO payload capacity of 8264 kg (18222 lbs) and an estimated cost per pound of $12,073. The highest capacity Titan 4 (Centaur and SRMU) has an estimated GTO payload capacity of 10496 kg (23144 lb), with an estimated cost of only $9,938 per pound. The best rate for the Titan 4 is not as low as the projected $7,500 per pound Ariane 5, but is considerably lower than any of the current Ariane 4 configurations.

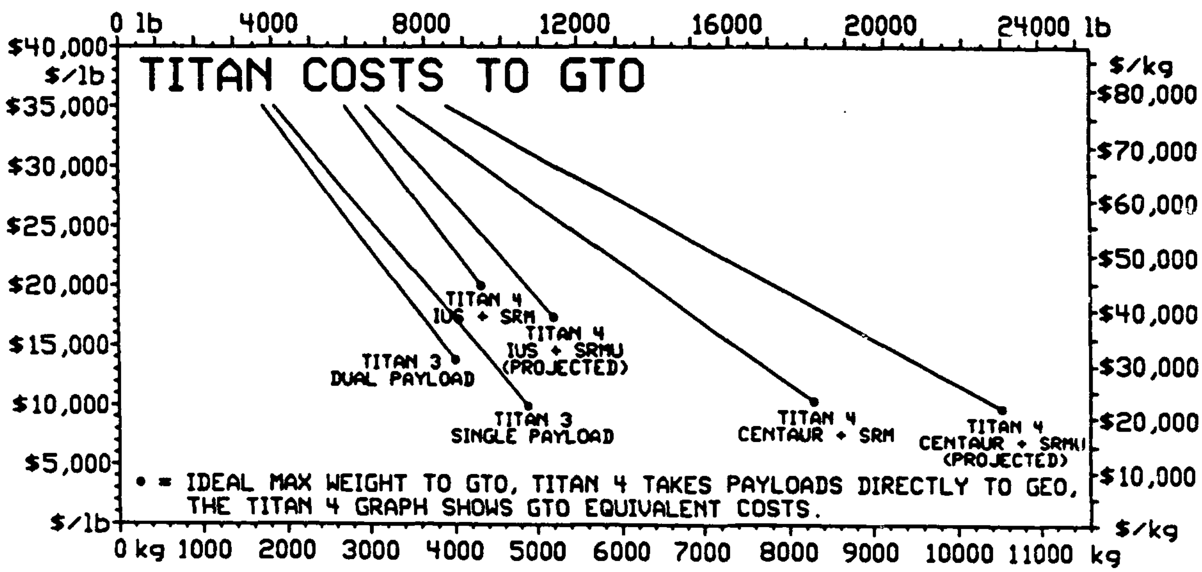

FIGURE 3-20. TITAN EQUIVALENT LAUNCH COSTS TO GTO

The commercial Titan 3 attempted four flights, and three successfully delivered their payloads to orbit including one dual payload which utilized 93% of the weight capacity. The dual payload flight used a modified military surplus upper stage because the payloads were too large for the smaller PAM, and cheaper than the larger IUS. The cost per pound rate for the 3713 kg (2166 lb) double satellite payload was about $14,902. Other flights carried a single payload commercial satellite weighing 4600 kg (10143 lb), and utilized 93% of the rated weight capacity, and for a cost per pound rate of $10,845.

The Titan 4 has carried two 2360 kg (5204 lb) military payloads to GEO for $36,510 per pound, with an equivalent GTO rate of $18,255. Both flights used the smallest, least efficient Titan 4 (IUS and SRM), and utilized 100% of the rated payload maximum for that configuration (Figure 3-21).

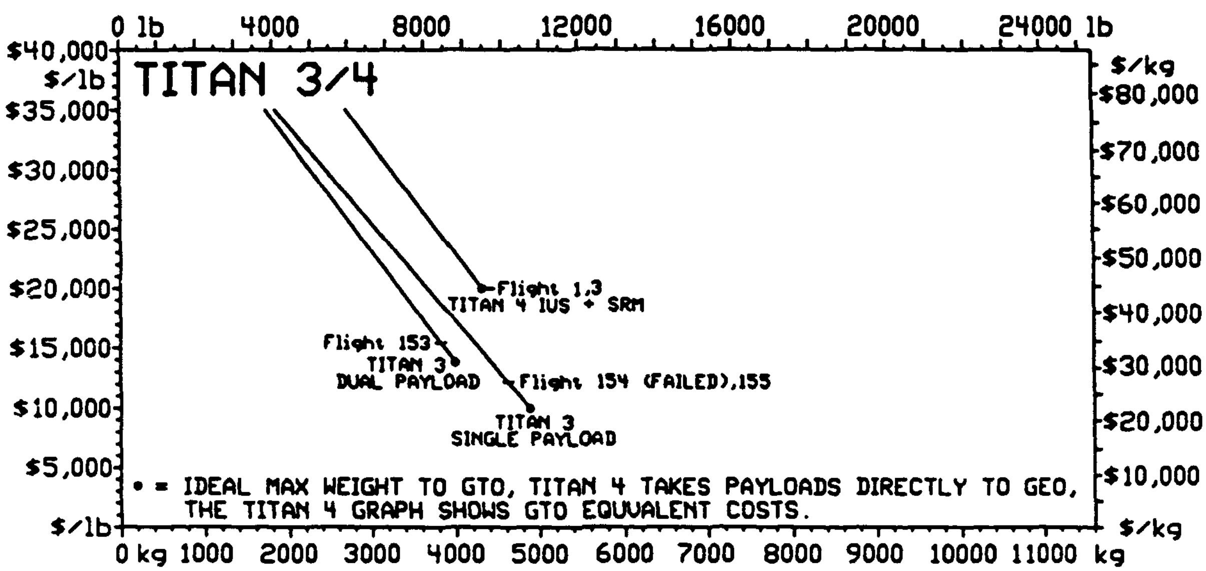

FIGURE 3-21. TITAN 3/4 FLIGHTS TO GTO

<u>Titan 3 and 4 Summary</u>. Titan space launch vehicles are different from other GTO launch vehicles, because the Titan was designed to go only to low-Earth orbit, whereas, most other vehicles go directly to a geostationary transfer orbit. The

disadvantage of the Titan concept is that the upper stage PAM, IUS, and TOS all require a third independent motor and guidance system, while other launch vehicles use only two. Commercial satellite manufacturers generally incorporate the GTO to GEO insertion motor and guidance system into the design of a satellite, whereas, military Titan contracted satellites leave the GEO insertion to the launch vehicle.

The Titan 3 has provided nearly thirty years delivery of satellites to GTO with optimum rates approaching $10,090 per pound. The multiple payload capacity of the Titan 3 provides tremendous versatility in carrying a variety of different sized satellites to low-Earth orbit (LEO), but GTO launches have been severely limited by the payload capacity of the PAM upper stage, and the IUS upper stage was entirely too expensive to be competitive.

The first flights of the Titan 4 were expensive because the optimum cost-saving performance upgrades, strap-on boosters and Centaur upper stage, were not available. Although the launch vehicle costs were higher, satellite costs were lower because the IUS and TOS upper stages eliminated the need for the satellite to have its own motor and GEO insertion control system. The projected cost of $9,938 for Titan 4 is considerably less than the Ariane 4, but not as low as the Ariane 5.

Launch Cost Summaries

Payload cost per pound rates are dependent on many factors, including launch configurations. The lowest rates are obtained when the maximum payload weight is utilized. On either side of the optimum payload weight, costs dramatically increased. If the payload weight is less than optimum, the customer must pay for the maximum weight anyway, since the launch vehicle must takeoff within its rated takeoff parameters in order to reliably make orbit. Space launch vehicle companies have had to carry dead weight, or ballast, when payloads came in under the maximum payload weight.

If the payloads are heavier than the maximum rated weight limit, a number of alternatives are available to solve the problem. First, maximum weight ratings can be reevaluated to determine their margin of safety. Are the ratings robust and can they carry the extra weight with a satisfactory level of confidence? Second, if the odds are questionable, the removal of hardware or fuel that least affect the reliability of mission success can be considered. The third alternative, and the most drastic, is to move up to the next size configuration. Finally, another launch company can be selected. Most companies took extreme measures not to lose a customer to another launch company.

Because of the numerous configurations and launch strategies being analyzed, data was refined to reflect comparable costs per pound. The vertical lines on the graphs illustrated the cost differences between the optimum rated weight configuration and the next larger configuration.

U.S. Launch Cost Summary

The U.S. currently has three proven (Atlas, Delta, and Titan) launch vehicle families capable of delivering geostationary payloads to orbit. The Pegasus/Taurus family has been rated for GEO payloads, but has not yet proven itself. Each launch vehicle family has been designed for specific size payloads with little overlap in capabilities (Figure 3-22). Each family is depicted by a series of jagged lines representing the costs for each vehicle configuration.

All four launch vehicles can offer flights at less than $11,000 per pound for a number of optimized weights. Some weights are not covered by reasonably priced flights because too few configurations are offered. The Atlas family has the most configurations and offers the best prices over a wider range than any other single payload U.S. launch vehicle. The Titan 3 offers a multiple payload option but it is not competitive and lacks standard upper stage options.

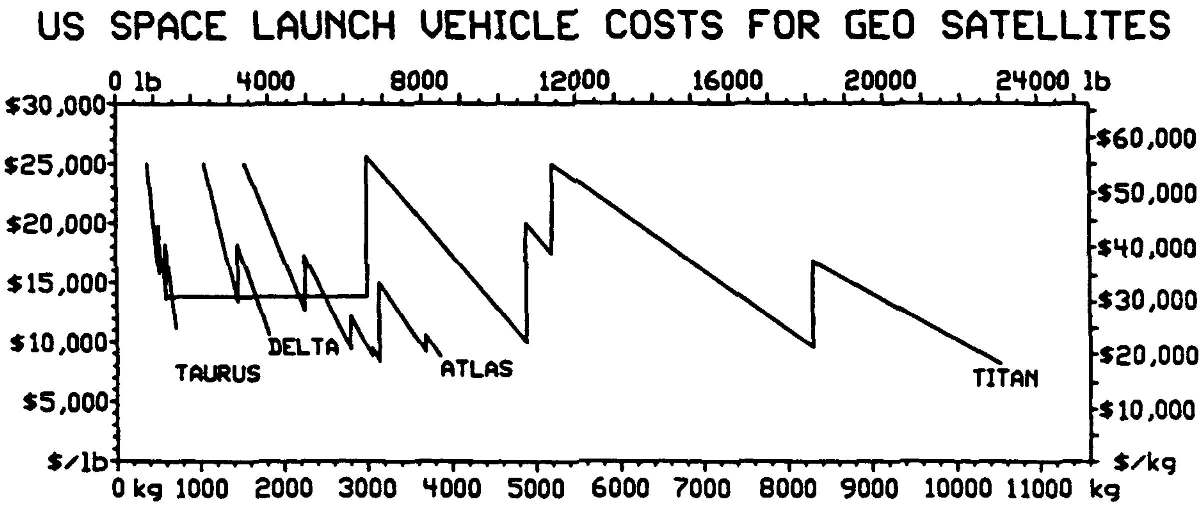

FIGURE 3-22. U.S. LAUNCH COST SUMMARY

Ariane Launch Cost Summary

Ariane offers 16 different launch configurations for the Ariane 4, which significantly overlap one another in an effort to keep the costs per pound low over a wide range of payload weights. Ariane's optimized rates vary from a low of $11,255 to a high of $14,918 per pound with an average, for all payloads up to 4460 kg (9834 lb), of about $14,000. No other launch family comes close to offering the same wide range of payload capacity at consistently low rates (Figure 3-23).

The Ariane 5 might, if cost projections are correct, offer rates of $7,500 per pound, which would be lower than the best Atlas 2AS rate ($8,881). The significance of the Ariane 5 is that it will be able to launch up to three satellites over an even wider range of payloads for about $9,000 per pound. Matching payloads to optimize maximum weight limits will be considerably easier with the addition of a third satellite option.

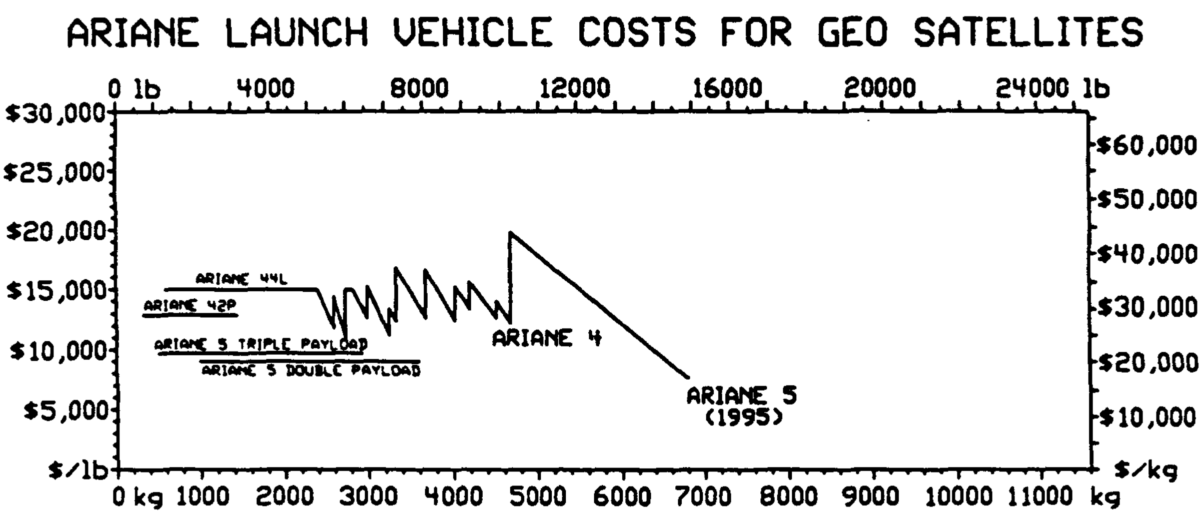

FIGURE 3-23. ARIANE LAUNCH COST SUMMARY

Launch Site Handicap

Ariane's Kourou launch site has a significant 15% efficiency advantage over the U.S. GEO launches from Cape Canaveral and Kennedy Space Center. Since GEO orbits are in a plane with the equator, less energy is needed to send a satellite to GEO from near the equator. Kourou is located only 4 degrees north of the equator, whereas, the U.S. launch facilities are north at 28.5 degrees. Plane changes from 28.5 degrees to the equator require about 15% more fuel to reach GEO than those launched from Kourou, yet U.S. launch vehicle companies have taken the blame for this handicap. An $8,500 cost per pound Ariane flight would have cost $10,000 per pound for an equal U.S. vehicle (Figure 3-24). When U.S. launch vehicles were compared equally with Ariane vehicles, incorporating the 15% handicap, U.S. launch vehicle costs were considerably less than Ariane for single payload configurations.

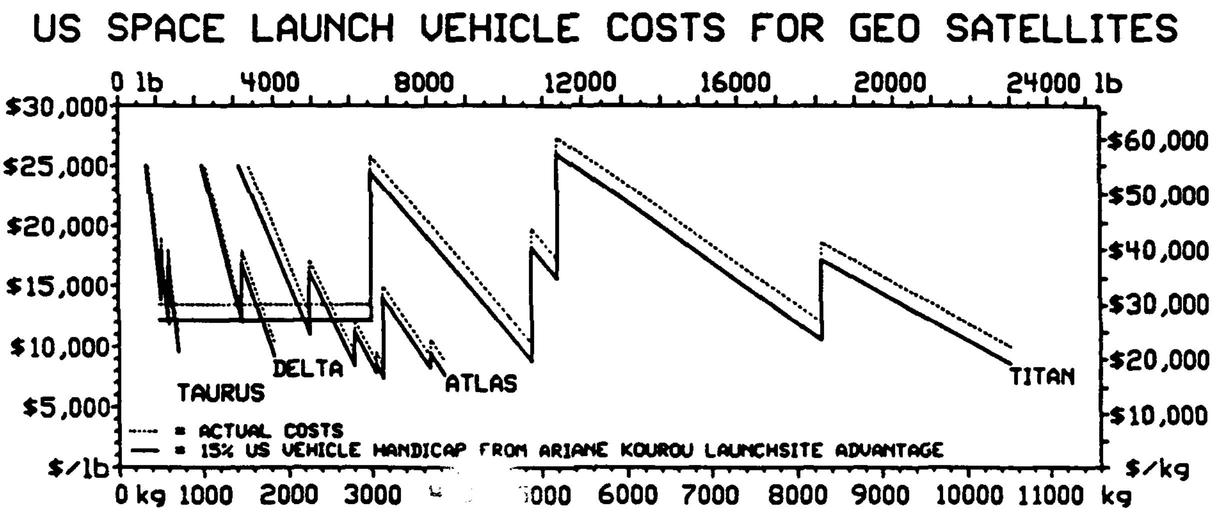

FIGURE 3-24. U.S. LAUNCH COSTS WITH 15% HANDICAP

World Launch Cost Summary

The complete launch cost picture becomes evident only after launch costs for each of the world's launch vehicle configurations are combined into one graph that compares payload weight to costs per pound (Figure 3-25). Every GEO space launch vehicle configuration has its own niche that covers a narrow band of payload weights at an acceptable rate.

The Russian Proton offers the lowest rates, $3,500 per pound, of any space launch vehicle to GEO, but it is plagued by commercial satellite trade launch restrictions. The Chinese CZ-2E has the second best rates, $6,354 per pound, and is also plagued by commercial satellite trade restrictions, too few flights, and excessive failures.

WORLD SPACE LAUNCH VEHICLE COSTS FOR GEO SATELLITES

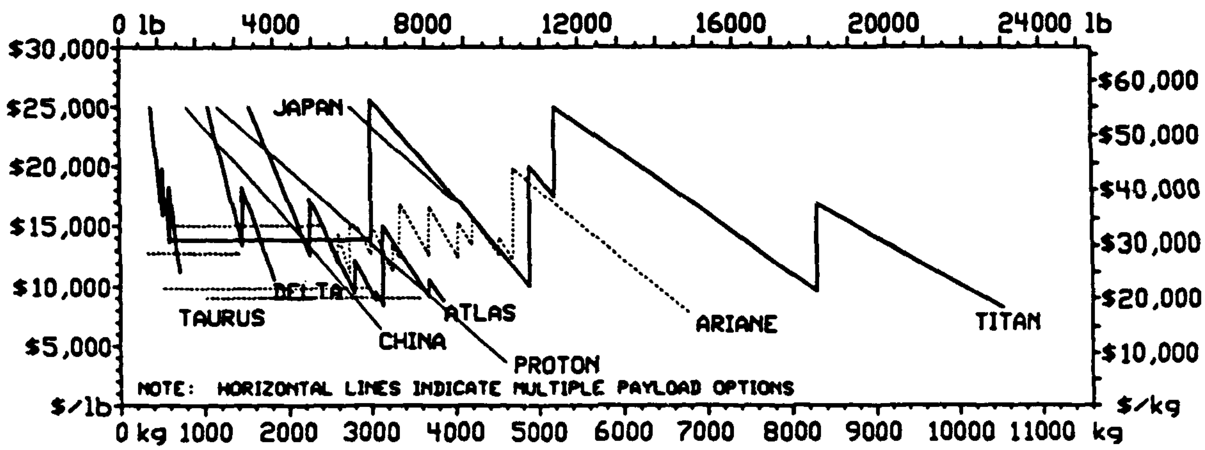

FIGURE 3-25. WORLD LAUNCH COSTS TO GTO

The third lowest rate, $8,881 per pound, is the Atlas 2AS. The fourth lowest rate, $10,090 per pound, is offered by the Titan 3, but commercial satellites don't weigh enough to utilize its large payload capacity and its multiple launch configuration is inefficient, because of excessive upper stage IUS costs. The fifth lowest rate, $10,721 per pound, is offered by Delta but is available only to the U.S. government and military customers. The sixth lowest rate, $11,091 per pound may soon be offered by the Taurus, but its payload capacity is too small for current GEO commercial satellites. All six of these launch vehicles offer rates less than Ariane, but their width of acceptable payload weights is very narrow.

The Japanese H1 and H2 costs have not been competitive because of the H1 learning curve using U.S. technology, and high H2 development costs. The success of the H2 has also been hindered by ecological restrictions limiting takeoffs to four per year.

Ariane, the world's first commercial space launch company, offers 16 different overlapping configurations that allow fairly consistent rates over a wide range of payload weights because maximum payload capacity is generally utilized. Single payload Ariane costs per pound have never matched the optimum launch costs of the Atlas, China's CZ-2E, Delta, Proton, Taurus, and Titan. Even though Ariane flights averaged $15,000 per pound, that rate was offered over payload weight ranges that were not covered by other launch vehicles.

End Notes

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CHAPTER IV

LAUNCH VEHICLE SELECTION

The next step in analyzing space launch vehicles was to review the launch vehicle selections made by each of the satellite owners for the five year period from 1988 to 1992. Launch vehicle selections were used to identify criteria that may help direct policy decisions concerning U.S. space programs.

1988 Launch Vehicle Selection

Fourteen commercial satellites were launched to GEO in 1988. Twelve of them by Ariane - ten with dual payload configurations and the remaining two with single payloads (Figure 4-1). The remaining two satellites were launched by the Japanese.

Although available, the lower cost Titan 3 option was rejected in favor of the Ariane in every case. The Titan 3 multiple payload configuration was probably rejected because it lacked an effective upper stage. One of the satellites launched aboard Ariane would have been a perfect match for the Delta 7925, but the civilian Delta rate ($14,460) very closely resembled the Ariane rate ($15,000). The Delta 7925 military rates were significantly lower than Ariane because of quantity pricing offered to the U.S. government. Delta's military rates were generally 20% less than their single flight commercial rates.

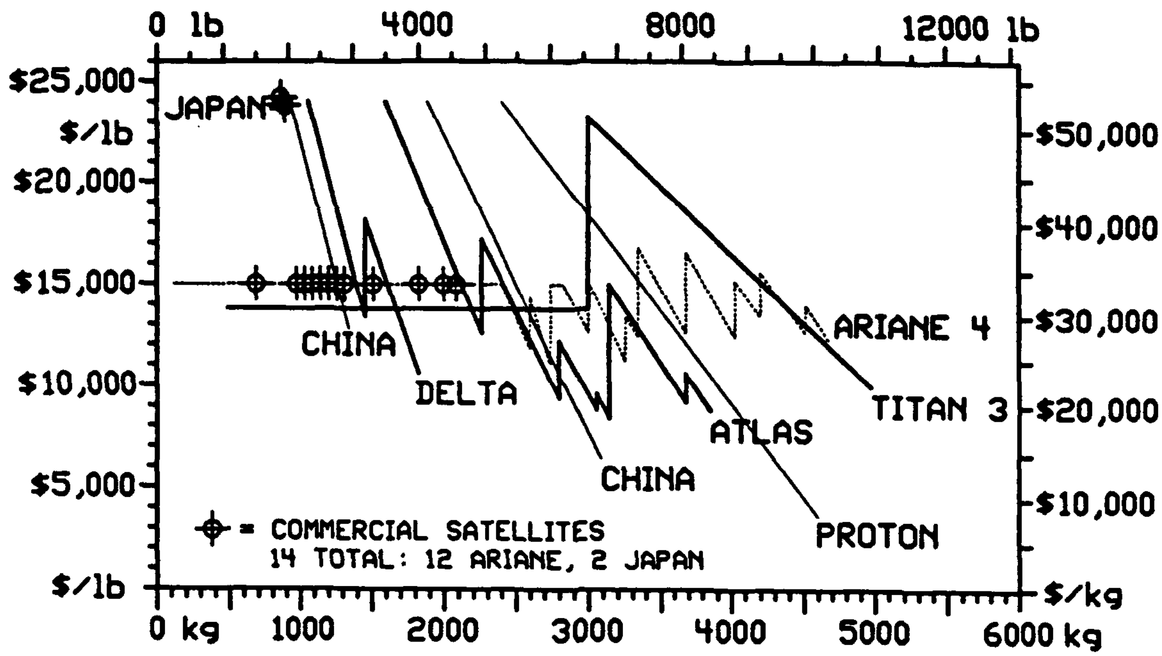

FIGURE 4-1. 1988 LAUNCH VEHICLE SELECTION

The two Japanese satellites were launched by Japanese H1, Delta-Japanese hybrid design, launch vehicles at about $23,500 per pound, which was too high to be competitive, but was considered part of the Japanese learning experience.

The Chinese did not launch any commercial satellites during 1988 even though the CZ-3 was available at a reasonable $12,860 per pound rate. They did launch two of their country's GEO communications satellites that were not considered commercial satellites because the Chinese never considered allowing their satellites to be launched commercially. In 1988, Ariane was considered the best option for the commercial satellites being launched into geostationary orbit.

1989 Launch Vehicle Selection

Of the eleven commercial satellites launched to GEO in 1989, nine were launched by Ariane (Figure 4-2). Six of the nine were delivered to GTO in dual payload configurations, and the remaining three were single payload flights. The other two satellites were launched by a U.S. Delta and a Japanese H1.

Once again the Titan 3, dual payload configuration, was rejected for reasons already described. Two of the larger satellites could have flown on Atlas 2 for a savings of $2000-$3000 per pound, but the commercial version of the Atlas was not available until the following year.

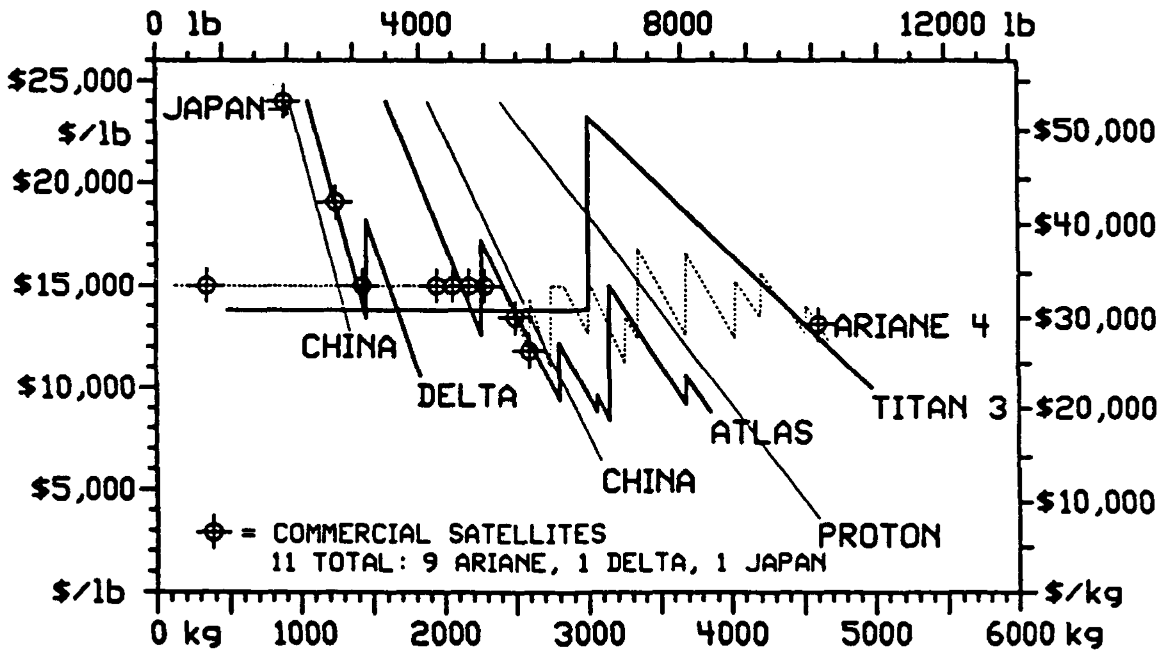

FIGURE 4-2. 1989 LAUNCH VEHICLE SELECTION

<u>1990 Launch Vehicle Selection</u>

Nineteen commercial satellites were launched to GEO in 1990. Eight by Ariane (Figure 4-3). All were delivered to GTO in dual payload configurations, requiring only four launch vehicles. China launched its first commercial satellite at a cost of about $13,500 per pound. Delta launched four satellites with launch costs much greater than Ariane, because three of the four flights were only about 85% of payload capacity . A Japanese commercial satellite was launched by an H1, Delta-Japanese hybrid design, at a cost of $23,500 per pound. The Shuttle also carried a military leased commercial satellite to LEO that was later boosted to GEO.

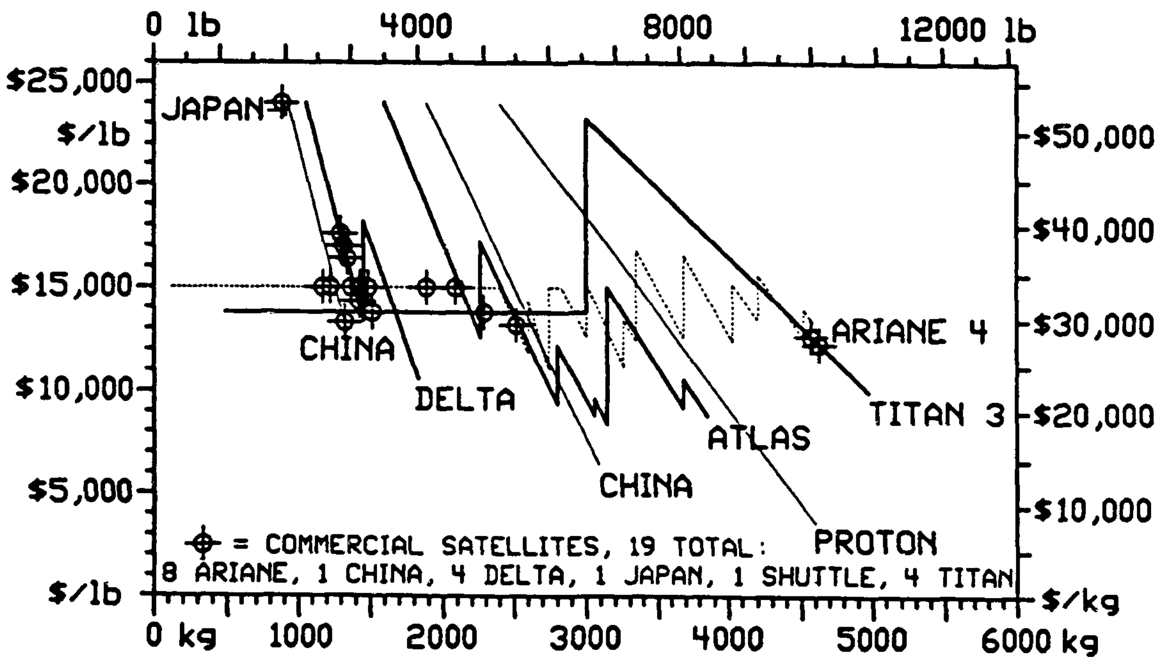

FIGURE 4-3. 1990 LAUNCH VEHICLE SELECTION

Titan 3s carried two large 4600 kg (10143 lb) Intelsat satellites for a cost of about $10,850 per pound, almost $1500 per pound less expensive than Ariane's Intelsat launch. Titan 3 also launched its first dual payload commercial flight using a surplus upper stage for a cost slightly less than Ariane could have provided.

Ariane failed to dominate the launches as they had during the two years before and two years after 1990 with U.S. vehicles launching nine of nineteen commercial satellites (or 47%). This was a significant achievement considering the small number of flights they launched the previous two years. But it was a short-lived achievement.

1991 Launch Vehicle Selection

Of the fifteen commercial satellites were launched to GEO in 1991, ten were launched by Ariane (Figure 4-4). Six were delivered to GTO in dual payload configurations. The other four Ariane launched satellites were well matched to the maximum single payload capacity of the launch vehicles and the costs averaged about $12,500 per pound. Another Japanese commercial satellite was launched by a Japanese H1, Delta-Japanese hybrid design, at a cost of $23,500 per pound. The Atlas attempted to deliver two commercial satellites to GTO, but only one of the launches was successful. The cost per pound rate for the Atlas flight was high because the payload only utilized 82.5% of the maximum rated payload capacity. Delta launched three satellites that averaged only 81% of the maximum payload capacity, so the rates were considerably higher than the optimum maximum payload rates.

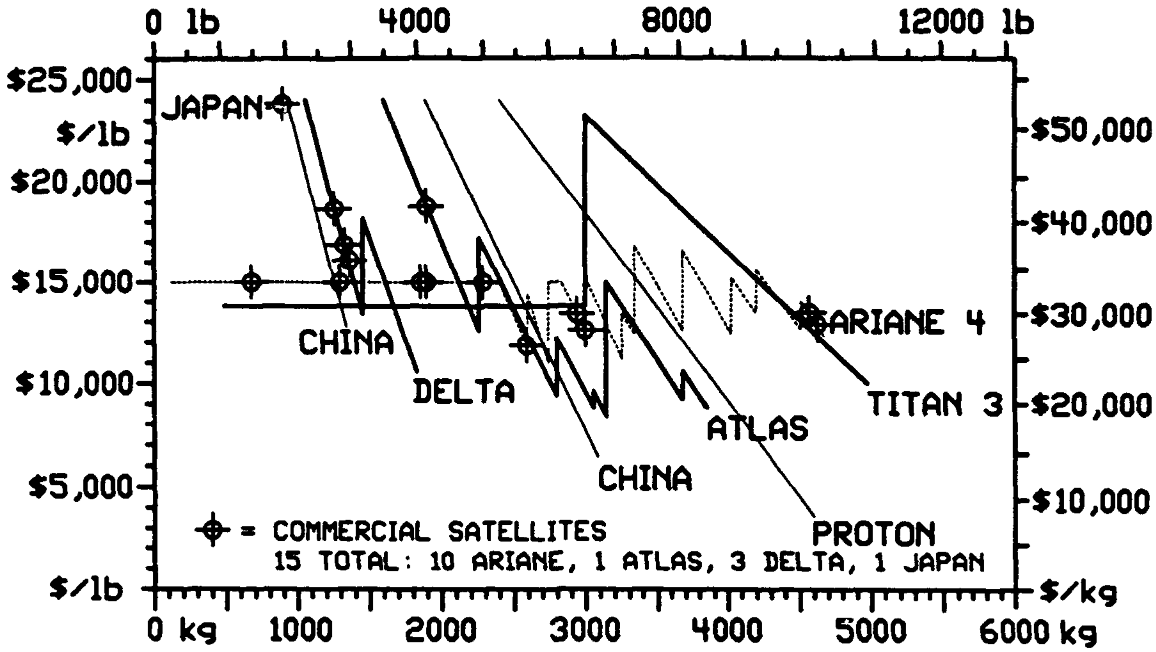

FIGURE 4-4. 1991 LAUNCH VEHICLE SELECTION

Ariane, again, dominated the commercial launch market by providing 67% of the flights to GEO in 1991. All of the U.S. launches cost more per pound than the Ariane because U.S. payloads failed to utilize maximum payload capacities of the launch vehicles.

1992 Launch Vehicle Selection

Sixteen commercial satellites were launched to GEO in 1992. Ten by Ariane (Figure 4-5) and eight of those were delivered in dual payload configurations for an average cost of $15,000 per pound. The other two Ariane launched satellites were

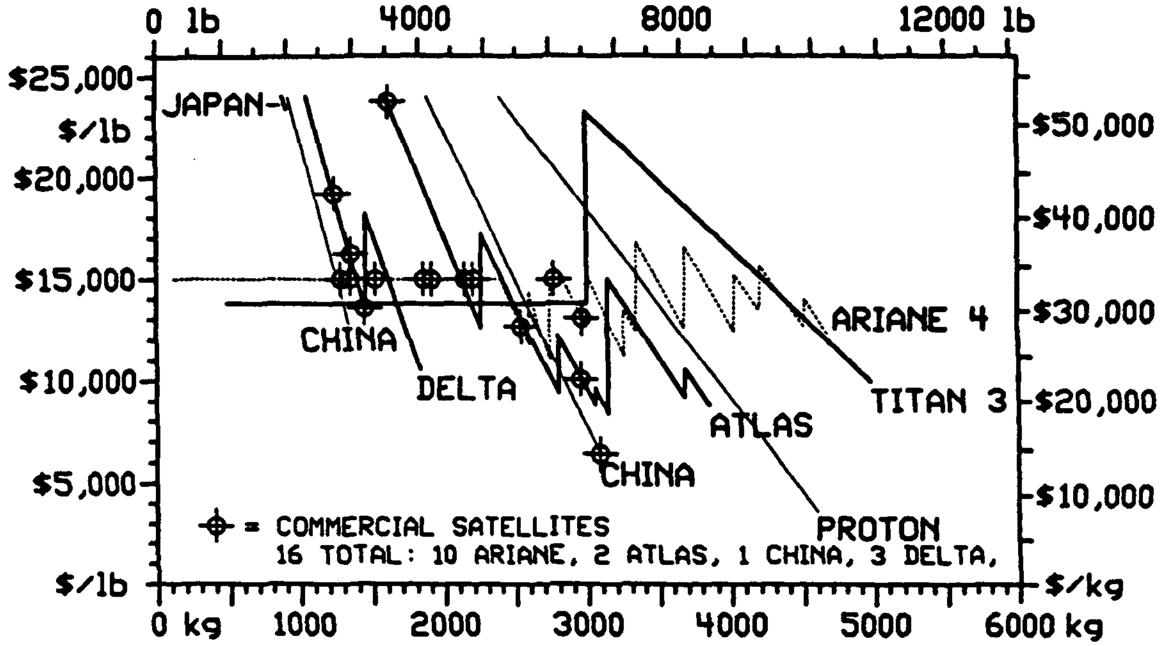

FIGURE 4-5. 1992 LAUNCH VEHICLE SELECTION

well matched to the maximum single payload capacity of the launch vehicles and the costs were near the optimum of about $12,000 per pound (Figure 4-5). The Atlas delivered two payloads to GTO. One was an excellent match and only cost about $9,600 per pound, whereas, the other only utilized 63% of the maximum payload capacity, and cost the customer considerably more. China delivered their first commercial payload aboard the CZ-2E at a charge (probably subsidized) of only about $6,300 per pound. Delta launched three satellites that averaged only 74% of the rated maximum payload capacity, so the costs per pound were considerably higher than Ariane. Ariane, once again, dominated the commercial launch market by launching 63% of the commercial satellites in 1992.

Launch Selection Conclusions

The commercial launch market for GEO satellites was dominated from 1988 to 1992 by Ariane primarily because its cost per pound rates were lower for the particular size commercial payloads that were being placed into GEO. Ariane could mix and match satellites to optimize the payload capacity of 16 different launch vehicle configurations. While other launch vehicles offered considerably lower rates for a single payload of a particular weight, they seldom matched the weights of the commercial satellites.

Launch vehicle selection decisions were found to be primarily dependent on the cost per pound rates offered by launch vehicle manufacturers. The lowest rate option was typically selected. The exceptions were evaluated to determine what other factors may have influenced a decision to select a more expensive launch vehicle. Why would Atlas and Delta satellite customers pay so much more per pound instead of contracting with the lower cost Ariane?

Eutelsat owners contracted an Atlas to launch one of their eight satellites at what seemed to be a much higher rate per pound. Why would a totally European communications consortium select an American launch vehicle to place a satellite in GEO over Europe, when all of the others were launched by the lower cost Ariane? The Atlas may have been selected many years earlier, when the Atlas was first introduced as a commercial launcher with competitive rates, but the weight of the Eutelsat satellite did not come close to utilizing the maximum payload capacity of the Atlas. Either the rates ended up higher than anticipated, or Eutelsat owners deliberately selected Atlas as a possible backup launch vehicle to Ariane.

The International Maritime Satellite Organization (Inmarsat) selected the more expensive Delta to launch their first two satellites. The selection decision for the first two satellites probably occurred in 1985, which was three years before the Ariane 4 made its maiden voyage. When they made the decision, the Delta was the best option. The smaller Ariane 2 and 3 were too small to handle the Inmarsat in the dual payload configuration, and the projected Ariane 4 had not yet proven itself. The next two Inmarsat satellites were delivered to GTO by the larger Ariane 4 in the dual payload configuration. The two future Inmarsat satellite launches have been contracted to Atlas because the later satellites have increased sufficiently in weight to take advantage of the lower cost Atlas in the single payload configuration. Inmarsat ownership seemed to make decisions based on launch costs.

A few of the satellite organizations may have made launch vehicle selection decisions based on the percentage of member-nation ownership. When launch costs between manufacturers were similar, ownership percentages may have influenced the decision. The International Telecommunications Satellite Organization (Intelsat), has been owned by over 100 different member nations, with varying percentage of controlling interest. Jane's Space Directory for 1993-94 listed the U.S. as owning 21%, whereas, European countries owned a slightly larger 25%. The U.S. owned nearly 27% a few years earlier when most of the flights were still contracted to U.S. launch manufacturers. Intelsat eventually reduced its use of U.S. launch vehicles from 100% (1984) to 50% by 1992, with Ariane picking up the difference. The increased use of Ariane was probably primarily due to reduced launch costs, with a few equal launch cost ties favoring Ariane because of the increased percentages of European ownership.

Loyalty to a particular launch vehicle manufacturer was more obvious for a small number of countries and satellite organizations (Appendix A). The European Space Agency (ESA), had used Ariane for seven of its nine launches, dating back to 1977. The exception to the use of Ariane occurred in 1977 and 1978 before Ariane became available. France was also loyal to Ariane for the launch of their 7 communications satellites because of their obvious ties to Arianespace. China and Russia have always launched all of their own satellites.

The remainder of the countries and satellite organizations demonstrated that launch costs had driven the selection decision. Even a country seemingly loyal to Ariane, contracted one of their five flights to Delta in 1992. Launch vehicle selections often changed when satellite payload weights increased, which was common for a family of satellites. This became additional evidence that optimum payload to launch vehicle matches, influenced launch vehicle selections.

A few unfortunate U.S. government decisions may have caused the loss of a number of commercial flights for the Titan 3. The commercial Titan 3 started launching payloads in 1990, only to be disrupted by a devastating decision to rebuild the only Titan 3 launch facility at Cape Canaveral Air Force Station, Florida. Why would any launch vehicle have only one launch facility? The only other geostationary Titan 3 launch facility (ETR41) was converted to a Titan 4 launch stand in 1989, which left the Titan 3 with only one GEO launch facility. There was a Titan 3 launch facility on the West Coast, but that was only capable of launching payloads to polar orbits, whereas, the East Coast facilities were only for launches to low inclination or geostationary orbits.

In 1990, half way through the year, Cape Canaveral ETR 40 Launch Pad, was closed for two years for a complete overhaul to accommodate all Titan 4 launch vehicles. Commercial Titan 3 launches to GTO were suspended during those two years, and many flights were lost to Ariane. The fact that there was only one Titan 3 launch facility for flights to GEO caused a significant loss of commercial business, especially when it was deliberately closed from 1990 to 1992.

The launch vehicle selection process was primarily driven by the cost per pound rate for delivering a satellite to orbit. Other launch decision considerations seemed to have little influence on the selection process. Since launch vehicle selections were made primarily from cost considerations, competitive pricing of U.S. launch vehicles became the primary goal.

CHAPTER V

LAUNCH VEHICLE TECHNOLOGY

U.S. space launch vehicles have been considered to be too costly and inefficient, because they use thirty year old launch vehicle technology. To determine the efficiency of launch vehicles, a number of criteria were identified and divided into three areas: (1) engine efficiency, (2) payload-to-takeoff weight ratios, and (3) reliability. These three criteria were then used to determine whether or not technology affected launch costs.

Engine Efficiency

Space travel was not possible until rocket engine designs achieved specific efficiencies. Before space launch vehicles became practical, three very important engine characteristics had to be optimized: (1) thrust, (2) impulse, and (3) specific impulse. The most important characteristic for launch vehicle engines has been specific impulse (Isp). The definition of specific impulse is the amount of thrust, divided by the quantity of fuel burned in one second. The amount of fuel, by weight, burned to produce a particular thrust, became the deciding factor for a successful engine design. Specific impulse, for this study, was used as the key efficiency rating for the comparison of rocket engines. A specific impulse of 300 has been considered good, and engineers typically have used 300 as the norm. Specific impulse ratings vary between the two major types of engines; solid propellent and liquid-fueled.

Solid propellent motors had Isp efficiency ratings between 200 and 325, with an average of about 275. The Titan SRMU solid propellent strap-on booster had the highest Isp, 324, of all the launch vehicle motors. The lowest Isp ratings were found in older, solid propellent boosters used by many launch vehicle manufacturers. Lower efficiency ratings were usually accompanied by lower costs, and solid propellent motors typically equalled liquid engine costs per pound.

Liquid-fueled engines have been capable of much higher Isp, ratings between 275 and 450, with an average of about 300. Kerosene-type liquid-fueled engines averaged an Isp of 300. A few engine designs have relied on liquid hydrogen and oxygen for efficiency ratings of over 400 Isp. Liquid hydrogen and oxygen engines have been more expensive, because they are more complicated than kerosene-type engines. Liquid hydrogen and oxygen engines also required that the fuels be stored at extremely low temperatures to maintain the hydrogen and oxygen in a liquid form. When these engines were designed properly, the weight savings generated potential additional income that more than compensated for the higher costs of the liquid hydrogen and oxygen engine.

Engine efficiencies were calculated for each family of launch vehicles, first and second stage, and then plotted on Figure 5-1. Engine efficiencies ranged between a low of 205 to a high of 451, with an average Isp of 318. Normal distribution standard deviation references were calculated and placed in the proper location. Standard deviations greater than +2 or less than -2 represented the extreme 5% of the engine efficiency ratings. Engine efficiencies with an Isp greater than 456, or +2 standard deviations, represented the upper 2.5% of the population, and were considered significantly better than the others. Engine efficiencies with an Isp less than 249, or -2 standard deviations, were considered significantly lower than the others, and represented the lower 2.5% of the population.

Engine efficiencies with an Isp's greater than 330 were only obtained with liquid hydrogen and oxygen engines. The Shuttle liquid hydrogen and oxygen main engine had the world's highest efficiency rating of 455 Isp. The second highest engine efficiency rating of 451 Isp was shared with Atlas 2AS, second stage, and the Japanese H2 second stage. The only launch vehicle manufacturer to use liquid hydrogen and oxygen engines for both the

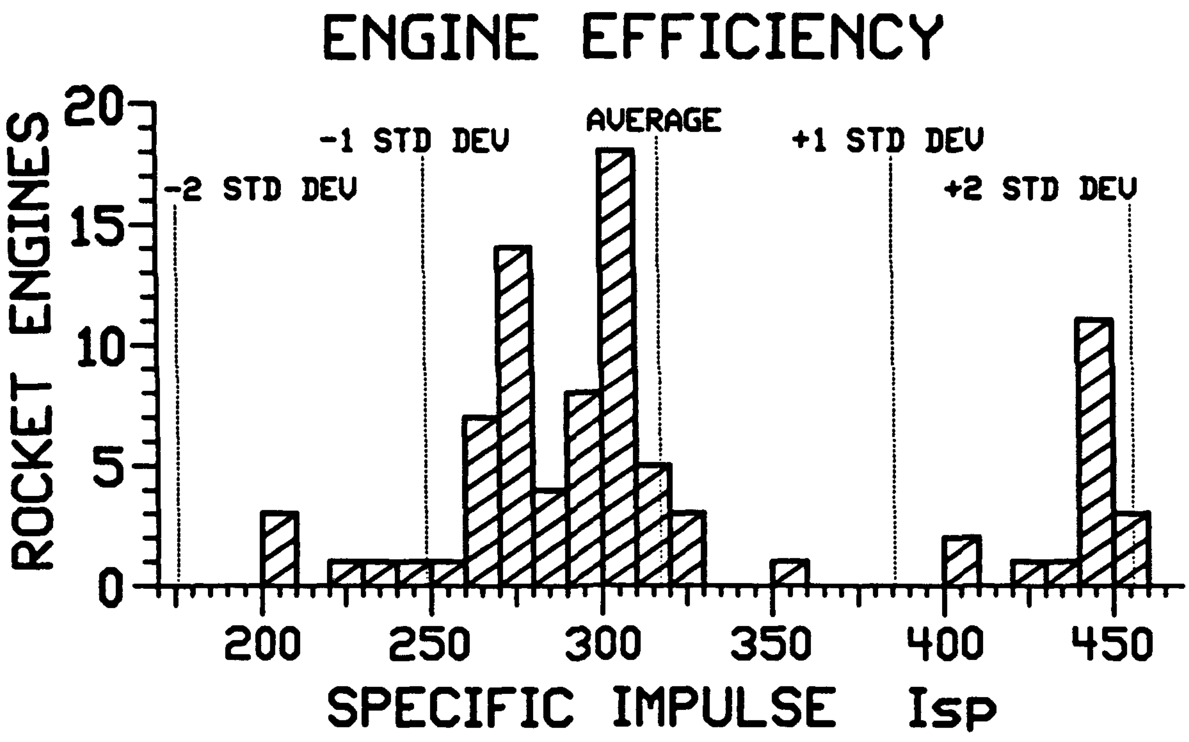

FIGURE 5-1. LIQUID ENGINE AND SOLID MOTOR EFFICIENCY

first and second stage, was the Japanese H2. All of the other Isp ratings above 330 were obtained with the Ariane 5, first stage, and the upper stages of the Atlas, Ariane, Chinese CZ-3, Japanese H1, and Titan.

Kerosene-type engine efficiencies averaged an Isp of 285. The highest efficiency ratings, 317 Isp, on a kerosene-type engine were given to the first stage engine of the Russian Proton, and the second stage of the Delta. The Russian Proton engine was designed over 30 years ago and kerosene-type engine efficiencies have not increased since then. The U.S. kerosene-type engines on the Atlas, Delta, and Titan averaged an Isp of 300. The Ariane 4 was designed with a conservative Isp rating of 278. Engine efficiency ratings have not increased for over 30 years, and no manufacturer seems to have gained a significant advantage over another in this area.

Engine Efficiency Summary. Liquid engine efficiencies have not improved for over 30 years, and all launch vehicle manufacturers have access to the latest technology. Solid propellent engine efficiencies have experienced gradual improvements of Isp. The latest version of the Titan strap-on booster, SRMU, has achieved the highest Isp rating, 324, of any solid booster ever designed. Many believe that the solution to reduced launch costs might be realized with this booster. Both Ariane and Japanese designers believe that the higher efficiency hydrogen and oxygen engines will be required in the future to be competitive. They may be right, if production costs can be reduced. The Ariane 5 and the Japanese H2, have both been designed to use liquid hydrogen and oxygen engines for the first stages. The Japanese have not been able to reduce the production costs of their H2 main engine and Ariane 5 main engine production costs are unknown. Shuttle designers received little credit for being the first to use the high performance liquid hydrogen and oxygen engines for the main stage of the Shuttle, because cost efficiencies never materialized.

Payload-to-Takeoff Weight Ratio

One very important launch vehicle performance criteria is the ability to carry the largest payload using the lightest launch vehicle. Expendable geostationary launch vehicles are consumed within minutes after launch, so they are designed to be as inexpensive per pound as possible. The lightest launch vehicles are not necessarily those providing the lowest cost per pound payload rates. A delicate balance exists between payload weight and takeoff weight. For example, a 1000 lb reduction in non-essential takeoff weight can allow an additional 1000 lb to be added to the payload. The costs incurred for launch vehicle weight reductions must never exceed the additional revenues generated. All weight reduction considerations must be carefully thought out to ensure cost effectiveness. Russian and Chinese launch vehicles were not considered in these ratios, because their launch costs were not confirmed, only their launch charges. Payload-to-takeoff weight ratios were relative indicators of space launch vehicle efficiency.

Payload-to-takeoff weight ratios were calculated for each family of launch vehicles, and then plotted on Figure 5-2. The average payload-to-takeoff weight ratio for GTO space launch vehicles was 0.92%. Less than 1% of the takeoff weight reached GTO, and only about 50% of that weight ever made it to GEO. More than 99% of the typical takeoff weight of a GTO launch vehicle was consumed during launch.

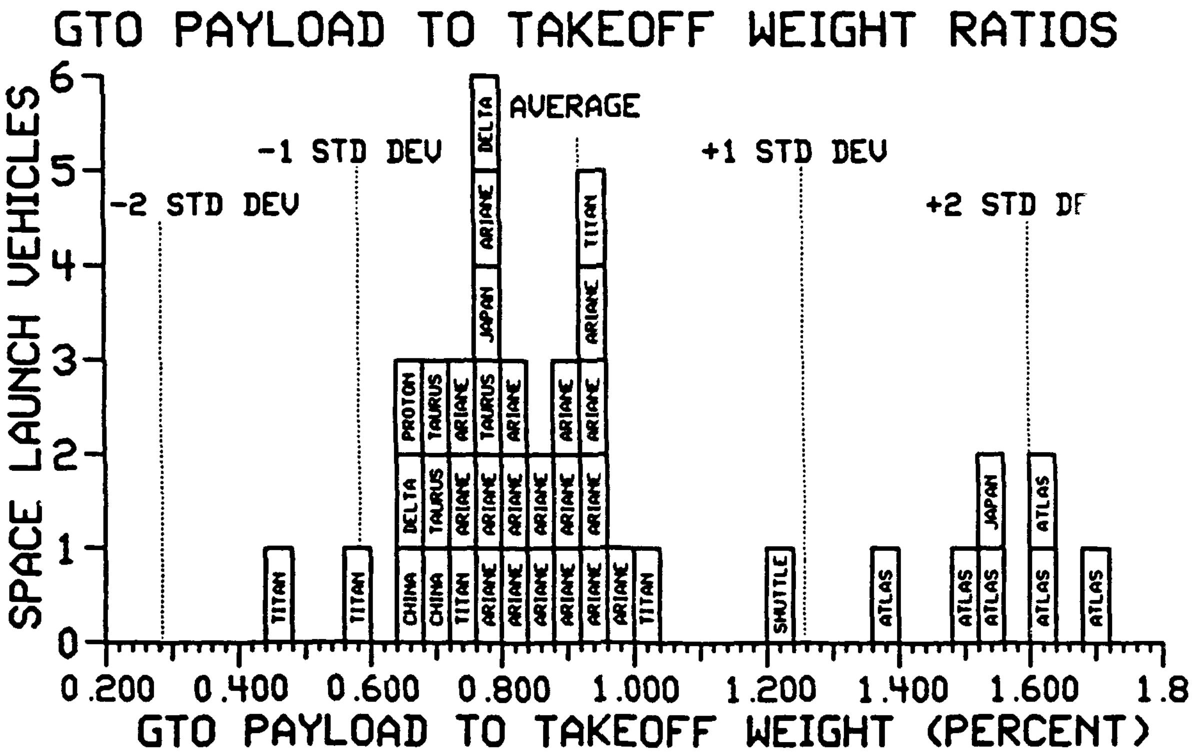

FIGURE 5-2. GTO PAYLOAD TO TAKEOFF WEIGHT RATIOS

Normal distribution standard deviation references were calculated and placed in the proper location. Standard deviations greater than +2, or less than -2, represented the extreme 5% of the payload-to-takeoff ratios. Ratios greater than 1.25% represented the upper 2.5% of the population, and were considered significantly better than the others. Ratios less than -2 standard deviations, 0.58%, were considered significantly lower than the others, and represented the lower 2.5% of the population.

Ariane. Ariane dominated the middle to high end of the payload-to-takeoff weight falling between a low of 0.732% (with the Ariane 44P, dual configuration), to a high ratio of 0.963% (with the Ariane 44LP, single payload configuration, H10+ upgrade). The lowest Ariane payload-to takeoff weight ratio, 0.732%, also had the unexpected lowest cost per pound rate of any of the Ariane family. This observation means that the less efficient Ariane solid propellent strap-on boosters were more cost effective than the more efficient liquid strap-on boosters. No other launch vehicles used liquid propellent strap-on boosters, so effectiveness comparisons were not possible.

Atlas. The complete Atlas family and the Japanese H2 were located in the region greater than +2 standard deviations. The best payload-to-takeoff weight ratio, 1.68%, was obtained by the Atlas 2A with the Block 1 modification, and was nearly twice that of the average ratio. The Atlas has a very high payload-to-takeoff weight ratio for three reasons: (1) a pressurized, light-weight, thin-walled, first stage fuel tank system that is lighter than any other launch vehicle, and (2) the use of liquid oxygen in the first stage, and (3) liquid oxygen and liquid hydrogen in the second stage. Liquid hydrogen and oxygen engines are more efficient and provide considerably more power for the amount of fuel consumed, but they have also been more expensive to manufacture. The payload-to-takeoff ratio went down when solid strap-on boosters were added to the Atlas, because solid motors were less efficient. The Atlas cost rates also went down slightly when the less expensive solid boosters were utilized.

Delta. The Delta 6925 and 7925 both, had low payload-to-takeoff weight ratios of 0.665, and 0.792%, but the ratio increased with each successive upgrade. The addition of nine small, less expensive solid propellent boosters on the Delta, helped to reduce the cost per pound rates. Another solid strap-on booster upgrade could lower the payload-to-takeoff ratio and again lower the cost per pound rates.

Japan. The Japanese H2 also had a significantly higher payload-to-takeoff weight ratio of 1.52% because it utilized a very efficient liquid hydrogen and oxygen first stage designed after the Shuttle main engine. The Japanese H2 $17,000 cost per pound launch rates were too high to be competitive because the development costs have been rolled back into the costs for each flight. The Japanese believe that the actual costs would only be about $6,800 per pound, once the development costs had been eliminated. With so few orders, and an ecological limitation of four flights per year, it will be difficult to reduce the production costs of the H2. The $6,800 payload costs per pound rates might be achieved if more investors were found and more flights were offered.

Titan. The Titan 4 is an excellent example of how upgrades can make a significant difference in the payload-to-takeoff ratio. The first configuration of Titan 4, with an IUS upper stage and the SRM strap-on booster, had the lowest payload-to-takeoff ratio of all the GTO launch vehicles, and the payload costs per pound were about $17,500. The payload-to-takeoff ratio went up considerably to 1.12% with the utilization of the older Atlas Centaur, liquid-fueled upper stage, and the world's most efficient solid strap-on boosters. This Titan 4 configuration has the highest payload-to-takeoff ratio of all the kerosene-type launch vehicles. The Titan 4, Centaur and SRMU configuration, payload rates went down to less than $10,000 per pound because the older Atlas Centaur upper stage was more efficient than the IUS upper stage. The Atlas Centaur upper stage and the SRMU solid strap-on boosters may provide the best competition for the upcoming Ariane 5.

Payload-to-Takeoff Weight Summary. Payload-to-takeoff weight ratios are a relative indicator of payload launch costs. Generally, the lowest payload cost per pound launch vehicles were also near the high end of the payload-to-takeoff weight ratios. More expensive vehicles were typically found at the low end of the payload-to-takeoff weight ratios. However, launch vehicles with efficient payload-to-takeoff weight ratios did not always reflect the lowest payload costs per pound. U.S. space launch vehicle manufacturers have been accused of being performance driven, which means that they may have put performance ratings before cost considerations. Low cost payload delivery must drive performance ratings in order to remain competitive. Maximum performance and efficiency ratings must not become the design goal, unless it results in the lowest payload costs per pound.

New launch vehicles have had low payload-to-takeoff weight ratios, but seldom performed as originally marketed because the first few flights were usually basic systems that did not push the design envelope. A number of flights are generally required to fully understand its characteristics and develop confidence in a new launch system before eventually being upgraded to peak performance. Most first flights fly with small, conservative payloads, or even dummy payloads, to develop confidence in the new design. Weight reduction programs became a normal occurrence after early flights proved that the initial designs were adequate.

Upgrading existing launch vehicles has been accomplished with a high degree of success and a tremendous amount of confidence by all of the world's space launch organizations. U.S. launch vehicle upgrades were typically done to accommodate larger, or different satellite payloads, and the older versions were typically phased out of production. Ariane, on the other hand, continually upgraded the Ariane 4, eventually fielding 16 different configurations that were all available to the customer. Ariane used upgrades as a means to offer reasonable prices over a wider range of payload weights.

Launch Vehicle Reliability

Launch vehicles have not always performed as expected, and the results have sometimes been disastrous. Reliability of launch vehicles has been first mathematically calculated, and then proven by numerous flights. Launch vehicles would never have failed, if engineered reliability estimates were true representations of fact. Launching payloads to a specific stellar location has been a difficult task in which every launch vehicle manufacturer has had their share of failures.

Space launch vehicle customers must select launch vehicle companies about five years before the anticipated launch date. Thus, they have to make difficult decisions concerning launch vehicle reliability many years before the actual flight. The only assurances available were launch warranties and payload insurance. Launch warranties include free reflights; payload insurance, covers a majority of satellite replacement costs.

Launch vehicle reliability rates were reviewed for GTO launch vehicle families from 1988 to 1992 (Figure 5-3, Part A and B). The Ariane 4 was launched 35 times, with only one failure for a success rate of 97.1%. General Dynamics launched 15 Atlas 1 and 2s, with 2 failures for a success rate of 86.7%. China launched 14 CZ-2E and CZ-3 launch vehicles, with 2 failures for a success rate of 85.7%. McDonnell Douglas launched 35 Delta 6925 and 7925 launch vehicles without any failures, for a success rate of 100%. Japan launched 7 H1 launch vehicles without any failures, for a success rate of 100%. Russia launched 52 Proton launch vehicles to GTO, with 3 failures for a success rate of 94%. NASA launched the Shuttle 27 times without any failures, for a success rate of 100%. Martin Marietta launched 17 Titan 3 and 4 launch vehicles with 2 failures, for a success rate of 88.2%. The average success rate for the GTO space launch vehicles from 1988 to 1992 was 94%.

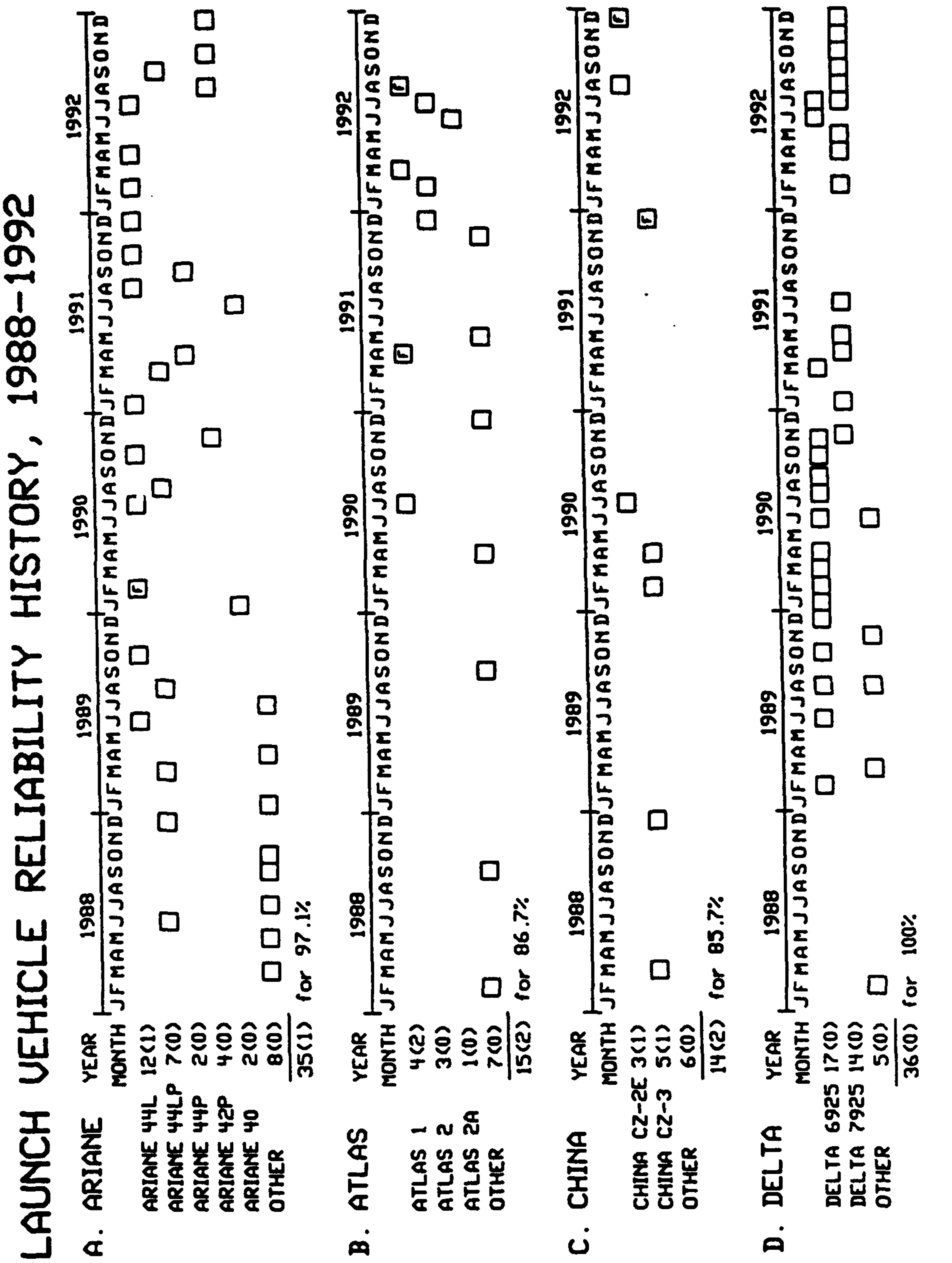

FIGURE 5-3 PART A. LAUNCH VEHICLE RELIABILITY, 1988-1992.

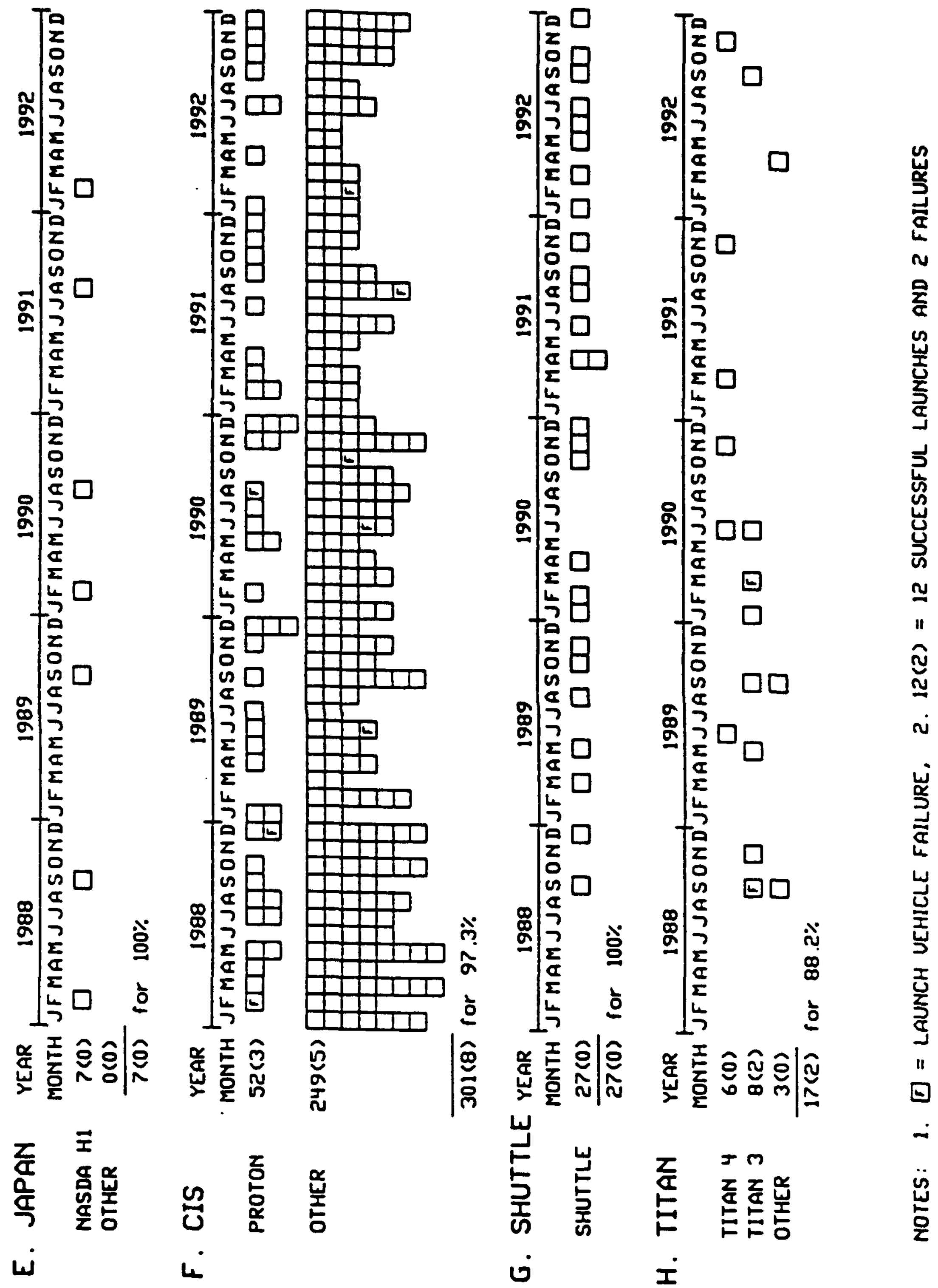

FIGURE 5-3 PART B. LAUNCH VEHICLE RELIABILITY, 1988-1992.

Launch vehicle success rates had little influence on the selection process for the eight major GTO space launch organizations. Even success rates as low as 85% have been considered acceptable when accompanied by sufficient launch warranties and payload insurance coverage. Space launch vehicle customers seemed very tolerant of launch vehicle organizations that were experiencing temporary setbacks, especially those customers that had contracted flights several years out because there was plenty of time to correct any problems. Even when launch companies were suffering from consecutive failures, customers for the upcoming flights never withdrew their payloads from the launch manifest for a number of reasons: (1) a rescheduled flight on another launch vehicle would have delayed the launch for about two years, (2) contract penalties would have been costly, and (3) launch vehicle problems would have been corrected before the next launch attempt. Those customers that lost satellites due to launch vehicle failures typically collected a percentage of the satellite construction costs from payload insurance and were offered free launches as part of the launch warranties.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Arianespace recognized the potential of commercial space transportation and built a line of launch vehicles tailored specifically to the needs of the world's commercial satellite owners.[1] The Ariane family of space launch vehicles was designed to deliver payloads directly to geostationary transfer orbit because commercial payloads were typically geostationary communications and observation satellites. They offer sixteen different launch configurations that cover a broad range of payload sizes, at consistently low prices. Ariane also offered multiple launch capability, allowing different sizes of satellites to be matched to one of the sixteen launch configurations. By so doing, they achieve a consistently high maximum payload. The Kourou (French Guiana) launch facility, located near the equator, provides a 15% energy savings over U.S. launched spacecraft bound for geostationary orbit.[2] The large family of Ariane space launch vehicles offers a number of significant advantages that explain why Arianespace captured the commercial launch market.

Nevertheless, the data shows that when Ariane launch vehicles are compared to equal size U.S. launch vehicles, the U.S. launch vehicles can be more economical in most cases. However, U.S. launch vehicles lack multiple launch capability and are capable of offering the lowest rates for only one size of satellite (the one that fits their maximum vehicle weight capacity). U.S. launch vehicles have offered considerably lower rates, typically 20%, for single payloads that utilized the maximum weight limits. Unfortunately, commercial payloads seldom matched the maximum weight limits of U.S. launch vehicles. The inevitable result was that most U.S. commercial launch vehicles flew with satellites that did not come close to filling up the payload area.

China, Japan, and Russia also have launch vehicles capable of providing competition with the United States. Currently they are being held at bay, because of U.S. satellite export restrictions which are enforceable only because U.S. companies still build most of the world's commercial satellites. The bad news is that foreign competition is growing.

After "bench marking" Ariane, by studying their performance strengths, a number of recommendations emerged that could be used by the U.S. to "catch-up" and "get ahead." Several of these recommendations involve funding outlays by the Department of Defense but the primary beneficiary appears to be the commercial space sector. While this may be true in part, the recommendations fit neatly within the Clinton Administration preferred "dual purpose" strategy whereby government spending benefits both the public and private sector. The recommended investments are relatively low cost but promise a high pay off.

Recommendation 1

Recommendation 1. The Department of Defense should fund a multiple payload option upgrade for the existing Atlas 1, 2, 2A, 2A Block 1, 2AS, and 2AS Block 1 configurations in order to compete with Ariane 4 multiple launch capability. They should also fund a multiple payload option (four or more satellites) upgrade the existing Titan 4, SRMU and Centaur configuration, in order to compete with the Ariane 5 multiple launch capability.

The most important difference between Ariane and U.S. launch vehicles is Ariane's ability to launch multiple payloads. This one advantage is the key to understanding why Ariane now dominates the commercial launch market. U.S. launch vehicles have full load rates as low as $7,500 per pound for the Atlas 2A, $9,300 for the Delta II 7925, and $8,800 for Titan 3, but their average costs for commercial satellites have been an incredibly high $17,500 per pound. Most of their launch vehicles flew with half empty cargo holds, because they were not able to match payloads to optimize the payload capacities.

The military Titan 3 has the same payload capacity as the Ariane 4 and has been launching dual payloads for the military for over twenty years. Titan 3 upgrades did not keep up with increasing commercial payload sizes and therefore were not competitive. The Titan 3 was also designed to be both a low-Earth and a GTO launch vehicle with design efficiency emphasis on low-Earth orbit injection. Because of the low-Earth design emphasis, the second stage must go to low-Earth orbit before sending the last stage on to a geostationary transfer orbit. This arrangement makes the Titan 3 less efficient at sending payloads to geostationary orbit. The Atlas, on the other hand, is a perfect candidate for a multiple payload configuration upgrade. The Atlas is smaller than the Ariane 4, but could lure many smaller payloads from Ariane. Ariane would then have a difficult time matching the larger payloads for multiple payload Ariane 4 and 5 configurations. Going after the smaller payloads is one way to regain part of the commercial launch market.

The Ariane 5, multiple launch configuration, will be capable of launching three satellites, which will provide a tremendous opportunity for Arianespace to match an even wider range of payloads to fill the spacecraft to its takeoff limit. Costs will be unbeatable unless the U.S. tops that with a Titan 4, SRMU and Centaur configuration, capable of launching four or more satellites to a geostationary transfer orbit. The Titan 4 also needs to be modified for a more efficient flight trajectory that would go directly to a geostationary transfer orbit instead of stopping at low-Earth orbit.

Recommendation 2

Recommendation 2. Fund economical launch vehicle upgrades which increase the number of launch configurations available, thus widening the payload window while keeping cost per pound rates low.

The second most significant technical advantage Ariane has is their ability to accommodate a wide variation of payload weights by using 16 different launch configurations. U.S. launch companies are forced to phase out older configurations when they are no longer needed for military payloads. Every effort should be made to increase the number of usable launch configurations for Atlas, Delta, and Titan launch vehicles.

Recommendation 3

Recommendation 3. The Department of Defense and commercial launch companies should build a launch facility near the equator to obtain a 15% savings in geostationary launch costs.

The third most significant advantage achieved by Ariane is their ability to launch from near the equator, which provides them with an immediate energy savings over comparable U.S. launch vehicles launched from Florida. A new U.S. launch facility would provide an immediate 15% cost savings for all flights to geostationary orbit. Ariane is not the only organization that will be taking advantage of equatorial launches; representatives from the Space Transportation Systems, Ltd., of Australia, and four Russian enterprises have signed an exclusive 20 year, $750 million contract, for commercial equatorial launch services from Papua, New Guinea. The Russians claim the Proton can lift an additional 40% payload from the equator over their own northern Baikonur Cosmodrome launch facility.[3] The U.S. already owns two islands near the equator that could be used for a new U.S. launch facility. Baker and Howland Islands, south of the Hawaiian Islands, are located closer to the equator than either New Guinea or Kourou. The initial investment would take many years to recover but the advantages may make the difference for U.S. space launch survival. A cost saving launch facility near the equator makes sense when one considers that geostationary satellites will be needed for decades to come.

Recommendation 4

Recommendation 4. Reduce the size and weight of future military satellites to conform with the size and weight of commercial satellites. This would benefit both the U.S. military and commercial launch sectors by providing common designs.

Military payloads have had the luxury of being designed with little concern for size and weight, which means that military payloads were seldom the same size and weight as commercial payloads. The Titan 3 was designed over thirty years ago, and is capable of carrying military payloads that are many times larger than most commercial payloads. The Titan 4 is also a very heavy lifter and is capable of carrying more than twice the weight of today's largest commercial payloads. By scaling back military satellites, common spacecraft can be used for launching both military and commercial payloads.

Recommendation 5

Recommendation 5. Continue and encourage the split of military and civilian space launch programs in order to provide the commercial sector enough freedom to make competitive choices and react quickly enough to catch commercial opportunities. Add a civilian contingent to both the U.S. Space Command management structure and the Pentagon with authority to influence military decisions that concern commercial launch issues.

Closing Remarks

The survival of U.S. commercial launch programs is in the hands of the Department of Defense until commercial programs can become autonomous. Ground operations, launch facilities, and space policies are largely government controlled, even though each of the three major launch companies (General Dynamics, McDonnell Douglas, and Martin Marietta) have their own commercial divisions and manufacture their own spacecraft. Too many military decisions are being made that negatively impact the future of the U.S. commercial launch business. Until commercial launch companies can break away from military entanglements, they will be unable to make the required decisions to ensure a future in the world's commercial launch market. On the other hand, selective Department of Defense funding of launch upgrades and a new launch site could establish a secure future for the U.S. commercial launch program.

In conclusion, unless something is done quickly to improve U.S. launch capabilities, it will never "catch-up" with the world's first commercial launch company, Arianespace. The U.S. government created the space sector and must ensure a smooth and effective split from the emerging commercial space program, in order to regain world dominance. Ariane, which is beginning to exercise significant influence on international trade rules, will fight any subsidized launch vehicles. This means U.S. government and commercial sector ties must be severed. However, the Department of Defense must consider commercial space launch interests when making decisions. Ariane provides an excellent "bench mark" for the U.S. to base future launch vehicle upgrades. If the U.S. sets the target of first equaling, and then surpassing, Ariane by incorporating these recommendations, the U.S. could once again dominate the world commercial launch market.

End Notes

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2. Ibid., p. 11.

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APPENDIX A
GEOSTATIONARY SATELLITES
1965-1993

NAME	LAUNCHED	LAUNCHER	ON STATION WEIGHT (kg)
INTERNATIONAL: Arab Satellite Communications Organization (ASCO)			
Arabsat 1A	8 Feb 85	Ariane	785
Arabsat 1B	18 Jun 85	Shuttle	785
Arabsat 1	26 Feb 92	Ariane	785
INTERNATIONAL: European Space Agency (ESA)			
Meteosat 1	23 Nov 77	Delta	322
OTS-2	12 May 78	Delta	444
Meteosat 2	18 Jun 81	Ariane	322
Marecs A	20 Dec 81	Ariane	680
Marecs B2	10 Nov 84	Ariane	680
Meteosat 3	15 Jun 88	Ariane	322
Meteosat 4	6 Mar 89	Ariane	316
Olympus 1	12 Jul 89	Ariane	1500
Meteosat 5	2 Mar 91	Ariane	316
INTERNATIONAL: Eutelsat (France, Spain, UK, and 31 others)			
Eutelsat 1-F1	16 Jun 83	Ariane	680
Eutelsat 1-F2	4 Aug 84	Ariane	680
Eutelsat 1-F4	16 Sep 87	Ariane	680
Eutelsat 1-F5	21 Jul 88	Ariane	700
Eutelsat 2-F1	30 Aug 90	Ariane	1123
Eutelsat 2-F2	15 Jan 91	Ariane	1123
Eutelsat 2-F3	7 Dec 91	Atlas	1123
Eutelsat 2-F4	9 Jul 92	Ariane	1123
INTERNATIONAL: Inmarsat (USA, UK, Norway, Japan, and 61 others)			
Inmarsat 2-F1	30 Oct 90	Delta	824
Inmarsat 2-F2	8 Mar 91	Delta	824
Inmarsat 2-F3	16 Dec 91	Ariane	824
Inmarsat 2-F4	12 Apr 92	Ariane	824
INTERNATIONAL: Intelsat (USA, UK, Japan, Germany, and 20 others)			
Intelsat 1	6 Apr 65	Delta	39
Intelsat 2-F2	11 Jan 67	Delta	86
Intelsat 3-F2	18 Dec 68	Delta	151
Intelsat 3-F3	5 Feb 69	Delta	151
Intelsat 3-F4	21 May 69	Delta	151

NAME	LAUNCHED	LAUNCHER	ON STATION WEIGHT (kg)
Intelsat 3-F6	14 Jan 70	Delta	151
Intelsat 3-F7	22 Apr 70	Delta	151
Intelsat 4-F2	25 Jan 71	Atlas	730
Intelsat 4-F3	19 Dec 71	Atlas	730
Intelsat 4-F4	22 Jan 72	Atlas	730
Intelsat 4-F5	13 Jun 72	Atlas	730
Intelsat 4-F7	23 Aug 73	Atlas	730
Intelsat 4-F8	21 Nov 74	Atlas	730
Intelsat 4-F6	20 Feb 75	Atlas	730
Intelsat 4-F1	22 May 75	Atlas	730
Intelsat 4A-F1	25 Sep 75	Atlas	825
Intelsat 4A-F2	29 Jan 76	Atlas	825
Intelsat 4A-F4	26 May 77	Atlas	825
Intelsat 4A-F3	6 Jan 78	Atlas	825
Intelsat 5-F2	6 Dec 80	Atlas	1012
Intelsat 5-F1	23 May 81	Atlas	1012
Intelsat 5-F3	15 Dec 81	Atlas	1012
Intelsat 5-F4	5 Mar 82	Atlas	1012
Intelsat 5-F5	28 Sep 82	Atlas	1012
Intelsat 5-F6	19 May 83	Atlas	1012
Intelsat 5-F7	19 Oct 83	Atlas	1012
Intelsat 5-F8	5 Mar 84	Ariane	1012
Intelsat 5A-F10	22 Mar 85	Atlas	1098
Intelsat 5A-F11	29 Jun 85	Atlas	1098
Intelsat 5A-F12	28 Sep 85	Atlas	1098
Intelsat 5A-F13	17 May 88	Ariane	1098
Intelsat 5A-F15	27 Jan 89	Ariane	1098
Intelsat 6-F2	27 Oct 89	Ariane	2546
Intelsat 6-F3	14 Mar 90/92	Titan/Shuttle	2546
Intelsat 6-F4	23 Jun 90	Titan	2546
Intelsat 6-F5	14 Aug 91	Ariane	2546
Intelsat 6-F1	29 Oct 91	Ariane	2546
Intelsat K	10 Jun 92	Atlas	1547
INTERNATIONAL: NATO			
NATO 2A	20 Mar 70	Delta	129
NATO 2B	2 Feb 71	Delta	129
NATO 3A	28 Apr 76	Delta	310
NATO 3B	28 Jan 77	Delta	310
NATO 3C	19 Nov 78	Delta	310
NATO 3D	13 Nov 84	Delta	295
NATO 4A	8 Jan 91	Delta	790
AUSTRALIA			
Optus A1	27 Aug 85	Shuttle	665
Optus A2	26 Nov 85	Shuttle	665

NAME	LAUNCHED	LAUNCHER	ON STATION WEIGHT (kg)
Optus A3	15 Sep 87	Ariane	665
Optus B1	13 Aug 92	CZ-3	1582
BRAZIL			
Brasilsat 1	8 Feb 85	Ariane	671
Brasilsat 2	28 Mar 86	Ariane	671
CANADA			
Anik A1	9 Nov 72	Delta	295
Anik A2	20 Apr 73	Delta	295
Anik A3	7 May 75	Delta	295
Anik B	16 Dec 78	Delta	474
Anik C3	11 Nov 82	Shuttle	563
Anik D1	26 Aug 82	Delta	633
Anik C2	18 Jun 83	Shuttle	563
Anik D2	2 Nov 84	Shuttle	633
Anik C1	13 Apr 85	Shuttle	563
Anik E2	4 Apr 91	Ariane	1781
Anik E1	26 Sep 91	Ariane	1781
CHINA			
STTW-T2	8 Apr 84	CZ-3	420
STTW-1	1 Feb 86	CZ-3	450
STTW-2	7 Mar 88	CZ-3	450
STTW-3	22 Dec 88	CZ-3	450
STTW-4	4 Feb 90	CZ-3	450
COMMONWEALTH of INDEPENDENT STATES (CIS)			
Cosmos 637	26 Mar 74	Proton	2000?
Molniya 1S	29 Jul 74	Proton	2000?
Raduga 1	22 Dec 75	Proton	1965
Raduga 2	11 Sep 76	Proton	1965
Ekran 1	26 Oct 76	Proton	1970
Raduga 3	23 Jul 77	Proton	1965
Ekran 2	20 Sep 77	Proton	1970
Raduga 4	18 Jul 78	Proton	1965
Gorizant 1	19 Dec 78	Proton	2120
Ekran 3	21 Feb 79	Proton	1970
Raduga 5	25 Apr 79	Proton	1965
Gorizant 2	5 Jul 79	Proton	2120
Ekran 4	3 Oct 79	Proton	1970
Gorizant 3	28 Dec 79	Proton	2120
Raduga 6	2 Feb 80	Proton	1965
Gorizant 4	14 Jun 80	Proton	2120

NAME	LAUNCHED	LAUNCHER	ON STATION WEIGHT (kg)
Ekran 5	15 Jul 80	Proton	1970
Raduga 7	5 Oct 80	Proton	1965
Ekran 6	12 Dec 80	Proton	1970
Raduga 8	18 Mar 81	Proton	1965
Ekran 7	26 Jun 81	Proton	1970
Raduga 9	30 Jul 81	Proton	1965
Raduga 10	9 Oct 81	Proton	1965
Ekran 8	5 Feb 82	Proton	1970
Gorizant 5	15 Mar 82	Proton	2120
Cosmos 1366	17 May 82	Proton	2000
Ekran 9	16 Sep 82	Proton	1970
Gorizant 6	20 Oct 82	Proton	2120
Raduga 11	26 Nov 82	Proton	1965
Ekran 10	12 Mar 83	Proton	1970
Raduga 12	8 Apr 83	Proton	1965
Gorizant 7	1 Jul 83	Proton	2120
Raduga 13	25 Aug 83	Proton	1965
Ekran 11	29 Sep 83	Proton	1970
Gorizant 8	30 Nov 83	Proton	2120
Raduga 14	15 Feb 84	Proton	1965
Cosmos 1540	6 Mar 84	Proton	2000
Ekran 12	16 Mar 84	Proton	1970
Cosmos 1546	29 Mar 84	Proton	2000
Gorizant 9	22 Apr 84	Proton	2120
Raduga 15	22 Jun 84	Proton	1965
Gorizant 10	1 Aug 84	Proton	2120
Ekran 13	24 Aug 84	Proton	1970
Gorizant 11	18 Jan 85	Proton	2120
Cosmos 1629	21 Feb 85	Proton	2000
Ekran 14	22 Mar 85	Proton	1970
Cosmos 1700	2 Oct 85	Proton	2000
Raduga 17	15 Nov 85	Proton	1965
Raduga 18	17 Jan 86	Proton	1965
Cosmos 1738	4 Apr 86	Proton	2000
Ekran 15	24 May 86	Proton	1970
Gorizant 12	10 Jun 86	Proton	2500
Raduga 19	25 Oct 86	Proton	1965
Gorizant 13	13 Nov 86	Proton	2500
Raduga 20	19 Mar 87	Proton	1965
Gorizant 14	11 May 87	Proton	2500
Ekran 16	3 Sep 87	Proton	1970
Cosmos 1888	1 Oct 87	Proton	2000
Cosmos 1894	28 Oct 87	Proton	2000
Cosmos 1897	26 Nov 87	Proton	2000
Raduga 21	10 Dec 87	Proton	1965
Ekran 17	27 Dec 87	Proton	1970
Gorizant 15	31 Mar 88	Proton	2500
Ekran 18	6 May 88	Proton	1970

NAME	LAUNCHED	LAUNCHER	ON STATION WEIGHT (kg)
Cosmos 1961	1 Aug 88	Proton	2000
Gorizant 16	18 Aug 88	Proton	2500
Raduga 22	20 Oct 88	Proton	1965
Gorizant 17	26 Jan 89	Proton	2500
Raduga 23	14 Apr 89	Proton	1965
Raduga 24	21 Jun 89	Proton	1965
Gorizant 18	5 Jul 89	Proton	2500
Gorizant 19	28 Sep 89	Proton	2500
Ekran 19	10 Dec 89	Proton	1970
Raduga 25	15 Dec 89	Proton	1965
Cosmos 2054	27 Dec 89	Proton	2000
Gorizant 20	20 Jan 90	Proton	2500
Raduga 26	15 Feb 90	Proton	1965
Cosmos 2085	18 Jul 90	Proton	2000
Gorizant 21	3 Nov 90	Proton	2500
Gorizant 22	23 Nov 90	Proton	2500
Raduga 27	20 Dec 90	Proton	1965
Raduga 28	27 Dec 90	Proton	1965
Raduga 29	28 Feb 91	Proton	1965
Gorizant 24	23 Oct 91	Proton	2500
Cosmos 2172	22 Nov 91	Proton	2000
Raduga 30	19 Dec 91	Proton	1965
Gorizant 25	2 Apr 92	Proton	2500
Gorizant 26	14 Jul 92	Proton	2500
Ekran 20	30 Oct 92	Proton	1970
Gorizant 27	27 Nov 92	Proton	2500
Raduga 31	25 Mar 93	Proton	1965
FRANCE			
Telecom 1A	4 Aug 84	Ariane	690
Telecom 1B	8 May 85	Ariane	690
Telecom 1C	11 Mar 88	Ariane	690
TDF-1	28 Oct 88	Ariane	1318
TDF-2	24 Jul 90	Ariane	1255
Telecom 2A	16 Dec 91	Ariane	1380
Telecom 2B	15 Apr 92	Ariane	1380
GERMANY			
TV-SAT	20 Nov 87	Ariane	1300
TV-SAT 2	8 Aug 89	Ariane	1300
DFS-1	5 Jun 89	Ariane	850
DFS-2	24 Jul 90	Ariane	850
DFS-3	12 Oct 92	Delta	850

NAME	LAUNCHED	LAUNCHER	ON STATION WEIGHT (kg)
HONG KONG			
Asiasat 1	8 Apr 90	CZ-3	620
INDIA			
Insat 1A	10 Apr 82	Delta	650
Insat 1B	30 Aug 83	Shuttle	650
Insat 1C	21 Jul 88	Ariane	650
Insat 1D	12 Jun 90	Delta	650
Insat 2A	9 Jul 92	Ariane	1162
INDONESIA			
Palapa A1	8 Jul 76	Delta	575
Palapa A2	10 Mar 77	Delta	575
Palapa B1	18 Jun 83	Shuttle	628
Palapa B2P	29 Mar 87	Delta	628
Palapa B2R	13 Apr 90	Delta	652
Palapa B4	14 May 92	Delta	692
ITALY			
Italsat 1	15 Jan 91	Ariane	890
JAPAN			
ETS 2	23 Feb 77	N1	130
GMS-1	14 Jul 77	Delta	315
CS-1	15 Dec 77	Delta	340
BSE	8 Apr 78	Delta	355
GMS-2	10 Aug 82	N2	292
CS-2A	4 Feb 83	N2	350
CS-2B	6 Aug 83	N2	350
BS-2A	23 Jan 84	N2	350
GMS-3	3 Aug 84	N2	303
BS-2B	12 Feb 86	N2	350
ETS 5	27 Aug 87	H1	550
CS-3A	19 Feb 88	H1	550
CS-3B	16 Sep 88	H1	550
JCSat 1	6 Mar 89	Ariane	1376
Superbird A	5 Jun 89	Ariane	1505
GMS-4	5 Sep 89	H1	325
JCSat 2	1 Jan 90	Titan	1376
BS-3A	28 Aug 90	H1	550
BS-3B	25 Aug 91	H1	550
Superbird B1	26 Feb 92	Ariane	1532
Superbird A1	1 Dec 92	Ariane	1665

NAME	LAUNCHED	LAUNCHER	ON STATION WEIGHT (kg)
LUXEMBOURG			
Astra 1A	11 Dec 88	Ariane	1043
Astra 1B	2 Mar 91	Ariane	1537
Astra 1C	12 Apr 93	Ariane	1700
MEXICO			
Morelos 1	18 Jun 85	Shuttle	666
Morelos 2	27 May 85	Shuttle	666
NORWAY			
Thor 1	18 Aug 90	Delta	660
SPAIN			
Hispasat 1A	10 Sep 92	Ariane	1325
SWEDEN			
Tele-X	2 Apr 89	Ariane	1277
UNITED KINGDOM			
Skynet 1	22 Nov 69	Delta	129
Skynet 1B	19 Aug 70	Delta	129
Skynet 2A	19 Jan 74	Delta	235
Skynet 2B	23 Nov 74	Delta	235
Skynet 4B	11 Dec 88	Ariane	790
Marcopolo 1	27 Aug 89	Delta	660
Skynet 4A	1 Jan 90	Titan	790
Skynet 4C	30 Aug 90	Ariane	790
USA: Alascom			
Aurora 2	29 May 91	Delta	750
USA: Alpha Lyracom			
PAS 1	15 Jun 88	Ariane	708
USA: AT&T			
Telstar 301	29 Jul 83	Delta	625
Telstar 302	30 Aug 84	Shuttle	625
Telsatr 303	17 Jun 85	Shuttle	625

NAME	LAUNCHED	LAUNCHER	ON STATION WEIGHT (kg)
USA: Comsat			
Marisat 1	19 Feb 76	Delta	362
Comstar D1	13 Mar 76	Atlas	911
Marisat 2	10 Jun 76	Delta	362
Comstar D2	22 Jul 76	Atlas	911
Marisat 3	14 Oct 76	Delta	362
Comstar D3	29 Jun 78	Atlas	911
SBS 1	15 Nov 80	Delta	546
Comstar D4	21 Feb 81	Atlas	911
SBS 2	24 Sep 81	Delta	546
SBS 3	11 Nov 82	Shuttle	546
USA: GE American			
Satcom 1	13 Dec 75	Delta	600
Satcom 2	26 Mar 76	Delta	598
Satcom 3	7 Dec 79	Delta	600
Satcom 3R	20 Nov 81	Delta	600
Satcom 4	16 Jan 82	Delta	600
Satcom 5	28 Oct 82	Delta	600
Satcom 6	11 Apr 83	Delta	600
Satcom 7	8 Sep 83	Delta	598
K-2	27 Nov 85	Shuttle	996
K-1	12 Jan 86	Shuttle	1021
C-1	20 Nov 90	Ariane	682
C-4	31 Aug 92	Delta	791
C-3	10 Sep 92	Ariane	789
USA: GTE Spacenet			
Spacenet 1	23 May 84	Ariane	692
Spacenet 2	10 Nov 84	Ariane	692
GStar 1	8 May 85	Ariane	759
ASC 1	27 Aug 85	Shuttle	665
GStar 2	28 Mar 86	Ariane	759
Spacenet 3R	11 Mar 88	Ariane	692
GStar 3	8 Sep 88	Ariane	759
GStar 4	20 Nov 90	Ariane	741
ASC 2/Spacenet 4	13 Apr 91	Delta	728
USA: Hughes Communications			
Westar 1	13 Apr 74	Delta	291
Westar 2	10 Oct 74	Delta	291
Westar 3	10 Aug 79	Delta	440
Westar 4	26 Feb 82	Delta	585
Westar 5	8 Jun 82	Delta	585

NAME	LAUNCHED	LAUNCHER	ON STATION WEIGHT (kg)
Galaxy 1	28 Jun 83	Delta	654
Galaxy 2	22 Sep 83	Delta	654
SBS 4	30 Aug 84	Shuttle	571
Leasat 2	30 Aug 84	Shuttle	1388
Galaxy 3	21 Sep 84	Delta	654
Leasat 1	8 Nov 84	Shuttle	1388
Leasat 3	12 Apr 85	Shuttle	1388
Leasat 4	29 Aug 85	Shuttle	1388
SBS 5	8 Sep 88	Ariane	725
Leasat 5	9 Jan 90	Shuttle	1388
SBS 6	12 Oct 90	Ariane	1514
Galaxy 6	12 Oct 90	Ariane	708
Galaxy 5	14 Mar 92	Atlas	800
Galaxy 7	28 Oct 92	Ariane	1680
USA: NASA			
ATS 1	7 Dec 66	Atlas	352
ATS 2	6 Apr 67	Atlas	370
ATS 3	6 Nov 67	Atlas	365
ATS 4	10 Aug 68	Atlas	392
ATS 5	12 Aug 69	Atlas	433
ATS 6	30 May 74	Titan	1402
TDRS 1	4 Apr 83	Shuttle	2120
TDRS 3	29 Sep 88	Shuttle	2120
TDRS 4	13 Mar 89	Shuttle	2120
TDRS 5	2 Aug 91	Shuttle	2120
TDRS 6	13 Jan 93	Shuttle	2120
USA: National Oceanic and Atmospheric Administration (NOAA/GOES)			
SMS 1	17 May 74	Delta	627
SMS 2	6 Feb 75	Delta	627
GOES 1	16 Oct 75	Delta	299
GOES 2	14 Jul 78	Delta	299
GOES 3	16 Jun 78	Delta	299
GOES 4	9 Sep 80	Delta	399
GOES 5	22 May 81	Delta	399
GOES 6	28 Apr 83	Delta	399
GOES 7	26 Feb 87	Delta	399
USA: Military			
Les 1	11 Feb 65	Titan	450
Les 2	6 May 65	Titan	450
Les 3	21 Dec 65	Titan	450
Les 4	21 Dec 65	Titan	450
IDCSP 1-7 (7 ea)	16 Jun 66	Titan	45 ea

NAME	LAUNCHED	LAUNCHER	ON STATION WEIGHT (kg)
IDCSP 8-15 (8 ea)	18 Jan 67	Titan	45 ea
IDCSP 16-18 (3 ea)	1 Jul 67	Titan	45 ea
Les 5	1 Jul 67	Titan	450
IDCSP 19-26 (8 ea)	13 Jun 68	Titan	45 ea
Les 6	26 Sep 68	Titan	450
Tacsat 1	9 Feb 69	Titan	725
DSP I #2/IMEWS	5 May 71	Titan	820
DSCS #1	3 Nov 71	Titan	590
DSCS #2	3 Nov 71	Titan	590
DSP I #3/IMEWS	1 Mar 72	Titan	820
DSP I #4/IMEWS	12 Jun 73	Titan	820
DSCS II #3	13 Dec 73	Titan	590
DSCS II #4	13 Dec 73	Titan	590
DSP I #5/IMEWS	14 Dec 75	Titan	820
Les 8	15 Mar 76	Titan	450
Les 9	15 Mar 76	Titan	450
DSP II #6	26 Jun 76	Titan	1100
DSP II #7	6 Feb 77	Titan	1100
DSCS II #7	12 May 77	Titan	450
DSCS II #8	12 May 77	Titan	450
Fltcom 1	9 Feb 78	Atlas	1180
DSCS II #9	25 Mar 78	Titan	450
DSCS II #10	25 Mar 78	Titan	450
DSCS II #11	14 Dec 78	Titan	450
DSCS II #12	14 Dec 78	Titan	450
Fltcom 2	4 May 79	Atlas	1180
DSP II #8	10 Jun 79	Titan	1100
DSCS II #13	21 Nov 79	Titan	450
DSCS II #14	21 Nov 79	Titan	450
Fltcom 3	17 Jan 80	Atlas	1180
Fltcom 4	30 Oct 80	Atlas	1360
DSP II #9	16 Mar 81	Titan	1100
Fltcom 5	6 Aug 81	Atlas	1360
DSP II #10	6 Mar 82	Titan	1100
DSCS III #1	30 Oct 82	Titan	1040
DSP II #11	15 Apr 84	Titan	1100
DSP II #12	22 Dec 84	Titan	1100
DSCS III #2	4 Oct 85	Shuttle	1040
DSCS III #3	4 Oct 85	Shuttle	1040
Fltcom 7	4 Dec 86	Atlas	1360
DSP II #13	29 Nov 87	Titan	1100
DSP III #14	14 Jun 89	Titan	1042
DSCS III #4	4 Sep 89	Titan	1040
Fltcom 8	25 Sep 89	Atlas	1360
DSP III #15	13 Nov 90	Titan	1042

APPENDIX B
ARIANE GEO LAUNCH VEHICLE FAMILY SUMMARIES
1988-1993

ARIANE 5

1.	Ariane 5	Name of Vehicle
2.	Arianespace	Manufacturing Company
3.	France	Country
4.	GTO	Orbit
5.	5500/5900/6800	Max Payload (kg) Triple/Dual/Single
6.	12127/13010/14994	Max Payload (lb) Triple/Dual/Single
7.	716,000	Takeoff Weight (kg)
8.	1,578,780	Takeoff Weight (lb)
9.	0.768/0.824/0.950	Payload to Takeoff Wt Ratio T/D/Single
10.	0	Number Launched to Date
11.	0	Number of Failures
12.	N/A	Success Rate
13.	$112.5M Projected	Cost per Flight in 1993 US Dollars
14.	$9277/8647/7503	Cost per Pound Max Load T/D/Single
15.	2	Number of Stages
16.	45.71-55.93	Overall Length (m) Fairing Differences
17.	5.4	Diameter (m)
18.	Liquid	First Stage Propellant (Liq or Solid)
19.	Liquid Hydrogen	First Stage Fuel
20.	Liquid Oxygen	First Stage Oxidizer
21.	156,200	First Stage Fuel Mass (kg)
22.	1,145	First Stage Thrust (kN), Vacuum
23.	433	First Stage Specific Impulse, Vacuum
24.	580	First Stage Duration of Thrust (Sec)
25.	2 ea Solid	Booster Quantity and Type
26.	HTPB	Booster Fuel
27.	HTPB	Booster Oxidizer
28.	237,200	Booster Fuel Mass (kg)
29.	6,000	Booster Thrust (Kn), Vacuum
30.	271.2	Booster Specific Impulse, Vacuum
31.	129.4	Booster Duration of Thrust (Sec)
32.	Liquid	Second Stage Propellant (Liq or Solid)
33.	MMH	Second Stage Fuel
34.	Nitrogen Tetroxide	Second Stage Oxidizer
35.	9,700	Second Stage Fuel Mass (kg)
36.	27.3	Second Stage Thrust (Kn), Vacuum
37.	318	Second Stage Specific Impulse, Vacuum
38.	115-1110	Second Stage Duration of Thrust (Sec)
39.	N/A	Third Stage Propellant (Liq or Solid)
40.	N/A	Third Stage Fuel
41.	N/A	Third Stage Oxidizer
42.	N/A	Third Stage Fuel Mass (kg)
43.	N/A	Third Stage Thrust (Kn), Vacuum
44.	N/A	Third Stage Specific Impulse, Vacuum
45.	N/A	Third Stage Duration of Thrust (Sec)

ARIANE 44L (Ariane 4 with 4 liquid add-on boosters)

1.	Ariane 44L	Name of Vehicle
2.	Arianespace	Manufacturing Company
3.	France	Country
4.	GTO	Orbit
5.	3800/4200/4460	Max Payload (kg) Dual/Single/H10+
6.	8379/9261/9834	Max Payload (lb) Dual/Single/H10+
7.	470,000	Takeoff Weight (kg)
8.	1,036,350	Takeoff Weight (lb)
9.	0.809/0.894/0.949%	Payload to Takeoff Wt Ratio Dual/S/H10+
10.	12	Number Launched to Date
11.	1	Number of Failures
12.	91.6%	Success Rate
13.	$125M	Cost per Flight in 1993 US Dollars
14.	$14918/13497/12711	Cost per Pound Max Load Dual/S/H10+
15.	3	Number of Stages
16.	57-59.8	Overall Length (m) Fairing Differences
17.	3.8	Diameter (m)
18.	Liquid	First Stage Propellant (Liq or Solid)
19.	UH25	First Stage Fuel
20.	Nitrogen Tetroxide	First Stage Oxidizer
21.	226,600	First Stage Fuel Mass (kg)
22.	2,708	First Stage Thrust (kN), Vacuum
23.	278	First Stage Specific Impulse, Vacuum
24.	205	First Stage Duration of Thrust (Sec)
25.	4 ea Liquid	Booster Quantity and Type
26.	UH25	Booster Fuel
27.	Nitrogen Tetroxide	Booster Oxidizer
28.	39,279	Booster Fuel Mass (kg)
29.	752	Booster Thrust (Kn), Vacuum
30.	278	Booster Specific Impulse, Vacuum
31.	142	Booster Duration of Thrust (Sec)
32.	Liquid	Second Stage Propellant (Liq or Solid)
33.	UH25	Second Stage Fuel
34.	Nitrogen Tetroxide	Second Stage Oxidizer
35.	34,000	Second Stage Fuel Mass (kg)
36.	786	Second Stage Thrust (Kn), Vacuum
37.	296	Second Stage Specific Impulse, Vacuum
38.	124	Second Stage Duration of Thrust (Sec)
39.	Liquid	Third Stage Propellant (Liq or Solid)
40.	Liquid Hydrogen	Third Stage Fuel
41.	Liquid Oxygen	Third Stage Oxidizer
42.	10,450	Third Stage Fuel Mass (kg)
43.	62	Third Stage Thrust (Kn), Vacuum
44.	447	Third Stage Specific Impulse, Vacuum
45.	725	Third Stage Duration of Thrust (Sec)

Ariane 44L, Flight 1 of 12

1.	V-31	Launch Reference Number
2.	5 Jun 89	Launch Date
3.	Kourou	Launch Facility
4.	Superbird A	Payload #1 Name of Satellite
5.	2492/5495	Payload #1 Launch Weight, kg/lb
6.	1505/3319	Payload #1 On-Orbit Weight, kg/lb
7.	DFS-1	Payload #2 Name of Satellite
8.	1416/3122	Payload #2 Launch Weight, kg/lb
9.	850/1874	Payload #2 On-Orbit Weight, kg/lb
10.	3908/8617	Total Payload Launch Weight, kg/lb
11.	2355/5193	Total On-Orbit Weight, kg/lb
12.	102.8%	Ratio of Launch Weight/Max Weight
13.	0.501%	Ratio of On-Orbit Wt/Takeoff Wt
14.	$14,506	Cost per Pound to GTO (Transfer Orbit)
15.	$24,071	Cost per Pound to GEO (Final Orbit)

Ariane 44L, Flight 2 of 12

1.	V-34	Launch Reference Number
2.	27 Oct 89	Launch Date
3.	Kourou	Launch Facility
4.	Intelsat 6-F2	Payload #1 Name of Satellite
5.	4600/10,143	Payload #1 Launch Weight, kg/lb
6.	2546/5614	Payload #1 On-Orbit Weight, kg/lb
7.	N/A	Payload #2 Name of Satellite
8.	N/A	Payload #2 Launch Weight, kg/lb
9.	N/A	Payload #2 On-Orbit Weight, kg/lb
10.	4600/10,143	Total Payload Launch Weight, kg/lb
11.	2546/5614	Total On-Orbit Weight, kg/lb
12.	109.5%	Ratio of Launch Weight/Max Weight
13.	0.542%	Ratio of On-Orbit Wt/Takeoff Wt
14.	$12,324	Cost per Pound to GTO (Transfer Orbit)
15.	$22,266	Cost per Pound to GEO (Final Orbit)

Ariane 44L, Flight 3 of 12 (Failed)

1.	V-36	Launch Reference Number
2.	22 Feb 90	Launch Date
3.	Kourou	Launch Facility
4.	Superbird B	Payload #1 Name of Satellite
5.	2492/5495	Payload #1 Launch Weight, kg/lb
6.	1505/3319	Payload #1 On-Orbit Weight, kg/lb
7.	BS-2X	Payload #2 Name of Satellite
8.	670/1477	Payload #2 Launch Weight, kg/lb
9.	402/886	Payload #2 On-Orbit Weight, kg/lb
10.	3162/6972	Total Payload Launch Weight, kg/lb
11.	1907/4205	Total On-Orbit Weight, kg/lb
12.	83.2%	Ratio of Launch Weight/Max Weight
13.	0.406%	Ratio of On-Orbit Wt/Takeoff Wt
14.	$17,929	Cost per Pound to GTO (Transfer Orbit)
15.	$29,727	Cost per Pound to GEO (Final Orbit)

Ariane 44L, Flight 4 of 12

1.	V-37	Launch Reference Number
2.	24 Jul 90	Launch Date
3.	Kourou	Launch Facility
4.	TDF-2	Payload #1 Name of Satellite
5.	2096/4622	Payload #1 Launch Weight, kg/lb
6.	1255/2767	Payload #1 On-Orbit Weight, kg/lb
7.	DFS-2	Payload #2 Name of Satellite
8.	1418/3127	Payload #2 Launch Weight, kg/lb
9.	850/1874	Payload #2 On-Orbit Weight, kg/lb
10.	3514/7749	Total Payload Launch Weight, kg/lb
11.	2105/4641	Total On-Orbit Weight, kg/lb
12.	92.5%	Ratio of Launch Weight/Max Weight
13.	0.448%	Ratio of On-Orbit Wt/Takeoff Wt
14.	$16,131	Cost per Pound to GTO (Transfer Orbit)
15.	$26,934	Cost per Pound to GEO (Final Orbit)

Ariane 44L, Flight 5 of 12

1.	V-39	Launch Reference Number
2.	12 Oct 90	Launch Date
3.	Kourou	Launch Facility
4.	SBS-6	Payload #1 Name of Satellite
5.	2478/5464	Payload #1 Launch Weight, kg/lb
6.	1514/3338	Payload #1 On-Orbit Weight, kg/lb
7.	Galaxy 6	Payload #2 Name of Satellite
8.	1212/2672	Payload #2 Launch Weight, kg/lb
9.	708/1561	Payload #2 On-Orbit Weight, kg/lb
10.	3690/8136	Total Payload Launch Weight, kg/lb
11.	2222/4899	Total On-Orbit Weight, kg/lb
12.	97.1%	Ratio of Launch Weight/Max Weight
13.	0.468%	Ratio of On-Orbit Wt/Takeoff Wt
14.	$15,364	Cost per Pound to GTO (Transfer Orbit)
15.	$25,515	Cost per Pound to GEO (Final Orbit)

Ariane 44L, Flight 6 of 12

1.	V-41	Launch Reference Number
2.	15 Jan 91	Launch Date
3.	Kourou	Launch Facility
4.	Italsat 1	Payload #1 Name of Satellite
5.	1865/4112	Payload #1 Launch Weight, kg/lb
6.	890/1962	Payload #1 On-Orbit Weight, kg/lb
7.	Eutelsat 2-F2	Payload #2 Name of Satellite
8.	1878/4141	Payload #2 Launch Weight, kg/lb
9.	866/1910	Payload #2 On-Orbit Weight, kg/lb
10.	3743/8253	Total Payload Launch Weight, kg/lb
11.	1756/3872	Total On-Orbit Weight, kg/lb
12.	98.5%	Ratio of Launch Weight/Max Weight
13.	0.374%	Ratio of On-Orbit Wt/Takeoff Wt
14.	$15,146	Cost per Pound to GTO (Transfer Orbit)
15.	$32,283	Cost per Pound to GEO (Final Orbit)

Ariane 44L, Flight 7 of 12

1.	V-45	Launch Reference Number
2.	14 Aug 91	Launch Date
3.	Kourou	Launch Facility
4.	Intelsat 6-F5	Payload #1 Name of Satellite
5.	4600/10,143	Payload #1 Launch Weight, kg/lb
6.	2546/5614	Payload #1 On-Orbit Weight, kg/lb
7.	N/A	Payload #2 Name of Satellite
8.	N/A	Payload #2 Launch Weight, kg/lb
9.	N/A	Payload #2 On-Orbit Weight, kg/lb
10.	4600/10,143	Total Payload Launch Weight, kg/lb
11.	2546/5614	Total On-Orbit Weight, kg/lb
12.	109.5%	Ratio of Launch Weight/Max Weight
13.	0.542%	Ratio of On-Orbit Wt/Takeoff Wt
14.	$12,324	Cost per Pound to GTO (Transfer Orbit)
15.	$22,266	Cost per Pound to GEO (Final Orbit)

Ariane 44L, Flight 8 of 12

1.	V-47	Launch Reference Number
2.	29 Oct 91	Launch Date
3.	Kourou	Launch Facility
4.	Intelsat 6 F1	Payload #1 Name of Satellite
5.	4600/10,143	Payload #1 Launch Weight, kg/lb
6.	2546/5614	Payload #1 On-Orbit Weight, kg/lb
7.	N/A	Payload #2 Name of Satellite
8.	N/A	Payload #2 Launch Weight, kg/lb
9.	N/A	Payload #2 On-Orbit Weight, kg/lb
10.	4600/10,143	Total Payload Launch Weight, kg/lb
11.	2546/5614	Total On-Orbit Weight, kg/lb
12.	109.5%	Ratio of Launch Weight/Max Weight
13.	0.542%	Ratio of On-Orbit Wt/Takeoff Wt
14.	$12,324	Cost per Pound to GTO (Transfer Orbit)
15.	$22,266	Cost per Pound to GEO (Final Orbit)

Ariane 44L, Flight 9 of 12

1.	V-48	Launch Reference Number
2.	16 Dec 91	Launch Date
3.	Kourou	Launch Facility
4.	Inmarsat 2 F3	Payload #1 Name of Satellite
5.	1310/2889	Payload #1 Launch Weight, kg/lb
6.	824/1817	Payload #1 On-Orbit Weight, kg/lb
7.	Telecom 2A	Payload #2 Name of Satellite
8.	2275/5016	Payload #2 Launch Weight, kg/lb
9.	1380/2889	Payload #2 On-Orbit Weight, kg/lb
10.	3585/7905	Total Payload Launch Weight, kg/lb
11.	2204/4860	Total On-Orbit Weight, kg/lb
12.	94.3%	Ratio of Launch Weight/Max Weight
13.	0.469%	Ratio of On-Orbit Wt/Takeoff Wt
14.	$15,813	Cost per Pound to GTO (Transfer Orbit)
15.	$25,720	Cost per Pound to GEO (Final Orbit)

Ariane 44L, Flight 10 of 12

1.	V-49	Launch Reference Number
2.	26 Feb 92	Launch Date
3.	Kourou	Launch Facility
4.	Arabsat 1C	Payload #1 Name of Satellite
5.	1310/2889	Payload #1 Launch Weight, kg/lb
6.	785/1731	Payload #1 On-Orbit Weight, kg/lb
7.	Superbird B1	Payload #2 Name of Satellite
8.	2560/5645	Payload #2 Launch Weight, kg/lb
9.	1532/3378	Payload #2 On-Orbit Weight, kg/lb
10.	3870/8533	Total Payload Launch Weight, kg/lb
11.	2317/5109	Total On-Orbit Weight, kg/lb
12.	101.8%	Ratio of Launch Weight/Max Weight
13.	0.493%	Ratio of On-Orbit Wt/Takeoff Wt
14.	$14,649	Cost per Pound to GTO (Transfer Orbit)
15.	$24,467	Cost per Pound to GEO (Final Orbit)

Ariane 44L+, Flight 11 of 12

1.	V-50	Launch Reference Number
2.	15 Apr 92	Launch Date
3.	Kourou	Launch Facility
4.	Telecom 2B	Payload #1 Name of Satellite
5.	2275/5016	Payload #1 Launch Weight, kg/lb
6.	1380/3043	Payload #1 On-Orbit Weight, kg/lb
7.	Inmarsat 2 F4	Payload #2 Name of Satellite
8.	1385/3054	Payload #2 Launch Weight, kg/lb
9.	824/1817	Payload #2 On-Orbit Weight, kg/lb
10.	3660/8070	Total Payload Launch Weight, kg/lb
11.	2204/4860	Total On-Orbit Weight, kg/lb
12.	82.6%	Ratio of Launch Weight/Max Weight
13.	0.469%	Ratio of On-Orbit Wt/Takeoff Wt
14.	$15,489	Cost per Pound to GTO (Transfer Orbit)
15.	$25,720	Cost per Pound to GEO (Final Orbit)

Ariane 44L, Flight 12 of 12

1.	V-51	Launch Reference Number
2.	9 Jul 92	Launch Date
3.	Kourou	Launch Facility
4.	Insat 2A	Payload #1 Name of Satellite
5.	1906/4203	Payload #1 Launch Weight, kg/lb
6.	1162/2562	Payload #1 On-Orbit Weight, kg/lb
7.	Eutelsat 2 F4	Payload #2 Name of Satellite
8.	1878/4141	Payload #2 Launch Weight, kg/lb
9.	1123/2476	Payload #2 On-Orbit Weight, kg/lb
10.	3784/8344	Total Payload Launch Weight, kg/lb
11.	2285/5038	Total On-Orbit Weight, kg/lb
12.	99.6%	Ratio of Launch Weight/Max Weight
13.	0.486%	Ratio of On-Orbit Wt/Takeoff Wt
14.	$14,981	Cost per Pound to GTO (Transfer Orbit)
15.	$24,811	Cost per Pound to GEO (Final Orbit)

ARIANE 44LP (Ariane 4 with 2 solid and 2 liquid add-on boosters)

1.	Ariane 44LP	Name of Vehicle
2.	Arianespace	Manufacturing Company
3.	France	Country
4.	GTO	Orbit
5.	3300/3700/4030	Max Payload (kg) Dual/Single/H10+
6.	7277/8159/8886	Max Payload (lb) Dual/Single/H10+
7.	418,500	Takeoff Weight (kg)
8.	922,793	Takeoff Weight (lb)
9.	0.789/0.884/0.963%	Payload to Takeoff Wt Ratio Dual/S/H10+
10.	7	Number Launched to Date
11.	0	Number of Failures
12.	100%	Success Rate
13.	$110M	Cost per Flight in 1993 US Dollars
14.	$14429/12869/12379	Cost per Pound Max Load Dual/S/H10+
15.	3	Number of Stages
16.	57-59.8	Overall Length (m) Fairing Differences
17.	3.8	Diameter (m)
18.	Liquid	First Stage Propellant (Liq or Solid)
19.	UH25	First Stage Fuel
20.	Nitrogen Tetroxide	First Stage Oxidizer
21.	226,600	First Stage Fuel Mass (kg)
22.	2,708	First Stage Thrust (kN), Vacuum
23.	278	First Stage Specific Impulse, Vacuum
24.	205	First Stage Duration of Thrust (Sec)
25.	2 Liquid/2 Solid	Booster Quantity and Type
26.	UH25/CTPB	Booster Fuel
27.	Nitrogen Tetroxide	Booster Oxidizer
28.	39,279/9,500	Booster Fuel Mass (kg)
29.	752/650	Booster Thrust (Kn), Vacuum/Sea Level
30.	278/201	Booster Specific Impulse, Vacuum
31.	142/28.8	Booster Duration of Thrust (Sec)
32.	Liquid	Second Stage Propellant (Liq or Solid)
33.	UH25	Second Stage Fuel
34.	Nitrogen Tetroxide	Second Stage Oxidizer
35.	34,000	Second Stage Fuel Mass (kg)
36.	786	Second Stage Thrust (Kn), Vacuum
37.	296	Second Stage Specific Impulse, Vacuum
38.	124	Second Stage Duration of Thrust (Sec)
39.	Liquid	Third Stage Propellant (Liq or Solid)
40.	Liquid Hydrogen	Third Stage Fuel
41.	Liquid Oxygen	Third Stage Oxidizer
42.	10,450	Third Stage Fuel Mass (kg)
43.	62	Third Stage Thrust (Kn), Vacuum
44.	447	Third Stage Specific Impulse, Vacuum
45.	725	Third Stage Duration of Thrust (Sec)

Ariane 44LP, Flight 1 of 7

1.	V-22	Launch Reference Number
2.	15 Jun 88	Launch Date
3.	Kourou	Launch Facility
4.	Meteosat 3	Payload #1 Name of Satellite
5.	696/1535	Payload #1 Launch Weight, kg/lb
6.	322/710	Payload #1 On-Orbit Weight, kg/lb
7.	PamAmSat 1	Payload #2 Name of Satellite
8.	1220/2690	Payload #2 Launch Weight, kg/lb
9.	708/1561	Payload #2 On-Orbit Weight, kg/lb
10.	1916/4225	Total Payload Launch Weight, kg/lb
11.	1030/2271	Total On-Orbit Weight, kg/lb
12.	58.1%	Ratio of Launch Weight/Max Weight
13.	0.246%	Ratio of On-Orbit Wt/Takeoff Wt
14.	$26,036	Cost per Pound to GTO (Transfer Orbit)
15.	$48,437	Cost per Pound to GEO (Final Orbit)

Ariane 44LP, Flight 2 of 7

1.	V-27	Launch Reference Number
2.	11 Dec 88	Launch Date
3.	Kourou	Launch Facility
4.	Skynet 4B	Payload #1 Name of Satellite
5.	1433/3160	Payload #1 Launch Weight, kg/lb
6.	790/1742	Payload #1 On-Orbit Weight, kg/lb
7.	Astra 1A	Payload #2 Name of Satellite
8.	1817/4006	Payload #2 Launch Weight, kg/lb
9.	1043/2300	Payload #2 On-Orbit Weight, kg/lb
10.	3250/7166	Total Payload Launch Weight, kg/lb
11.	1833/4042	Total On-Orbit Weight, kg/lb
12.	98.5%	Ratio of Launch Weight/Max Weight
13.	0.39%	Ratio of On-Orbit Wt/Takeoff Wt
14.	$15,350	Cost per Pound to GTO (Transfer Orbit)
15.	$27,214	Cost per Pound to GEO (Final Orbit)

Ariane 44LP, Flight 3 of 7 (Failed)

1.	V-29	Launch Reference Number
2.	6 Mar 89	Launch Date
3.	Kourou	Launch Facility
4.	JCSat 1	Payload #1 Name of Satellite
5.	2280/5027	Payload #1 Launch Weight, kg/lb
6.	1376/3034	Payload #1 On-Orbit Weight, kg/lb
7.	Meteosat 4	Payload #2 Name of Satellite
8.	681/1502	Payload #2 Launch Weight, kg/lb
9.	316/697	Payload #2 On-Orbit Weight, kg/lb
10.	2961/6529	Total Payload Launch Weight, kg/lb
11.	1692/3731	Total On-Orbit Weight, kg/lb
12.	89.7%	Ratio of Launch Weight/Max Weight
13.	0.404%	Ratio of On-Orbit Wt/Takeoff Wt
14.	$16,848	Cost per Pound to GTO (Transfer Orbit)
15.	$29,482	Cost per Pound to GEO (Final Orbit)

Ariane 44LP, Flight 4 of 7

1.	V-33	Launch Reference Number
2.	8 Aug 89	Launch Date
3.	Kourou	Launch Facility
4.	Hipparcos	Payload #1 Name of Satellite
5.	1140/2514	Payload #1 Launch Weight, kg/lb
6.	617/1360	Payload #1 On-Orbit Weight, kg/lb
7.	TV-Sat 2	Payload #2 Name of Satellite
8.	2145/4730	Payload #2 Launch Weight, kg/lb
9.	1300/2867	Payload #2 On-Orbit Weight, kg/lb
10.	3285/7243	Total Payload Launch Weight, kg/lb
11.	1917/4227	Total On-Orbit Weight, kg/lb
12.	99.5%	Ratio of Launch Weight/Max Weight
13.	0.458%	Ratio of On-Orbit Wt/Takeoff Wt
14.	$15,187	Cost per Pound to GTO (Transfer Orbit)
15.	$26,023	Cost per Pound to GEO (Final Orbit)

Ariane 44LP, Flight 5 of 7

1.	V-38	Launch Reference Number
2.	30 Aug 90	Launch Date
3.	Kourou	Launch Facility
4.	Eutelsat 2 F1	Payload #1 Name of Satellite
5.	1878/4141	Payload #1 Launch Weight, kg/lb
6.	1123/2476	Payload #1 On-Orbit Weight, kg/lb
7.	Skynet 4C	Payload #2 Name of Satellite
8.	1433/3160	Payload #2 Launch Weight, kg/lb
9.	790/1742	Payload #2 On-Orbit Weight, kg/lb
10.	3311/7301	Total Payload Launch Weight, kg/lb
11.	1913/4218	Total On-Orbit Weight, kg/lb
12.	100.3%	Ratio of Launch Weight/Max Weight
13.	0.457%	Ratio of On-Orbit Wt/Takeoff Wt
14.	$15,066	Cost per Pound to GTO (Transfer Orbit)
15.	$26,079	Cost per Pound to GEO (Final Orbit)

Ariane 44LP, Flight 6 of 7

1.	V-42	Launch Reference Number
2.	2 Mar 91	Launch Date
3.	Kourou	Launch Facility
4.	Astra 1B	Payload #1 Name of Satellite
5.	2580/5689	Payload #1 Launch Weight, kg/lb
6.	1537/3389	Payload #1 On-Orbit Weight, kg/lb
7.	Meteosat 5	Payload #2 Name of Satellite
8.	681/1502	Payload #2 Launch Weight, kg/lb
9.	316/697	Payload #2 On-Orbit Weight, kg/lb
10.	3261/7190	Total Payload Launch Weight, kg/lb
11.	1853/4086	Total On-Orbit Weight, kg/lb
12.	98.8%	Ratio of Launch Weight/Max Weight
13.	0.443%	Ratio of On-Orbit Wt/Takeoff Wt
14.	$15,299	Cost per Pound to GTO (Transfer Orbit)
15.	$26,921	Cost per Pound to GEO (Final Orbit)

Ariane 44LP+, Flight 7 of 7

1.	V-53	Launch Reference Number
2.	10 Sep 92	Launch Date
3.	Kourou	Launch Facility
4.	Hispasat 1A	Payload #1 Name of Satellite
5.	2194/4838	Payload #1 Launch Weight, kg/lb
6.	1325/2922	Payload #1 On-Orbit Weight, kg/lb
7.	Satcom C3	Payload #2 Name of Satellite
8.	1375/3032	Payload #2 Launch Weight, kg/lb
9.	789/1740	Payload #2 On-Orbit Weight, kg/lb
10.	3569/7870	Total Payload Launch Weight, kg/lb
11.	2114/4661	Total On-Orbit Weight, kg/lb
12.	102.0%	Ratio of Launch Weight/Max Weight
13.	0.505%	Ratio of On-Orbit Wt/Takeoff Wt
14.	$13,977	Cost per Pound to GTO (Transfer Orbit)
15.	$23,600	Cost per Pound to GEO (Final Orbit)

ARIANE 42L (Ariane 4 with 2 liquid add-on boosters)

1.	Ariane 42L	Name of Vehicle
2.	Arianespace	Manufacturing Company
3.	France	Country
4.	GTO	Orbit
5.	2800/3200/3350	Max Payload (kg) Dual/Single/H10+
6.	6174/7056/7387	Max Payload (lb) Dual/Single/H10+
7.	363,000	Takeoff Weight (kg)
8.	800,415	Takeoff Weight (lb)
9.	0.771/0.882/0.923%	Payload to Takeoff Wt Ratio Dual/S/H10+
10.	1	Number Launched to Date
11.	0	Number of Failures
12.	100%	Success Rate
13.	$94M	Cost per Flight in 1993 US Dollars
14.	$15225/13322/12725	Cost per Pound Max Load Dual/S/H10+
15.	3	Number of Stages
16.	57-59.8	Overall Length (m) Fairing Differences
17.	3.8	Diameter (m)
18.	Liquid	First Stage Propellant (Liq or Solid)
19.	UH25	First Stage Fuel
20.	Nitrogen Tetroxide	First Stage Oxidizer
21.	226,600	First Stage Fuel Mass (kg)
22.	2,708	First Stage Thrust (kN), Vacuum
23.	278	First Stage Specific Impulse, Vacuum
24.	205	First Stage Duration of Thrust (Sec)
25.	2 ea Liquid	Booster Quantity and Type
26.	UH25	Booster Fuel
27.	Nitrogen Tetroxide	Booster Oxidizer
28.	39,279	Booster Fuel Mass (kg)
29.	752	Booster Thrust (Kn), Vacuum
30.	278	Booster Specific Impulse, Vacuum
31.	142	Booster Duration of Thrust (Sec)
32.	Liquid	Second Stage Propellant (Liq or Solid)
33.	UH25	Second Stage Fuel
34.	Nitrogen Tetroxide	Second Stage Oxidizer
35.	34,000	Second Stage Fuel Mass (kg)
36.	786	Second Stage Thrust (Kn), Vacuum
37.	296	Second Stage Specific Impulse, Vacuum
38.	124	Second Stage Duration of Thrust (Sec)
39.	Liquid	Third Stage Propellant (Liq or Solid)
40.	Liquid Hydrogen	Third Stage Fuel
41.	Liquid Oxygen	Third Stage Oxidizer
42.	10,450	Third Stage Fuel Mass (kg)
43.	62	Third Stage Thrust (Kn), Vacuum
44.	447	Third Stage Specific Impulse, Vacuum
45.	725	Third Stage Duration of Thrust (Sec)

Ariane 42L, Flight 1 of 1

1.	V-56	Launch Reference Number
2.	12 May 93	Launch Date
3.	Kourou	Launch Facility
4.	Astra 1C	Payload #1 Name of Satellite
5.	2790/6152	Payload #1 Launch Weight, kg/lb
6.	1700/3749	Payload #1 On-Orbit Weight, kg/lb
7.	Arsene (Not GEO)	Payload #2 Name of Satellite
8.	151/333	Payload #2 Launch Weight, kg/lb
9.	96/212	Payload #2 On-Orbit Weight, kg/lb
10.	2941/6485	Total Payload Launch Weight, kg/lb
11.	1796/3960	Total On-Orbit Weight, kg/lb
12.	99.6%	Ratio of Launch Weight/Max Weight
13.	0.495%	Ratio of On-Orbit Wt/Takeoff Wt
14.	$14,495	Cost per Pound to GTO (Transfer Orbit)
15.	$23,737	Cost per Pound to GEO (Final Orbit)

ARIANE 44P (Ariane 4 with 4 solid add-on boosters)

1.	Ariane 44P	Name of Vehicle
2.	Arianespace	Manufacturing Company
3.	France	Country
4.	GTO	Orbit
5.	2600/3000/3290	Max Payload (kg) Dual/Single/H10+
6.	5733/6615/7254	Max Payload (lb) Dual/Single/H10+
7.	355,000	Takeoff Weight (kg)
8.	782,775	Takeoff Weight (lb)
9.	0.732/0.845/0.927%	Payload to Takeoff Wt Ratio Dual/S/H10+
10.	2	Number Launched to Date
11.	0	Number of Failures
12.	100%	Success Rate
13.	$84M	Cost per Flight in 1993 US Dollars
14.	$14652/12698/11580	Cost per Pound Max Load Dual/S/H10+
15.	3	Number of Stages
16.	57-59.8	Overall Length (m) Fairing Differences
17.	3.8	Diameter (m)
18.	Liquid	First Stage Propellant (Liq or Solid)
19.	UH25	First Stage Fuel
20.	Nitrogen Tetroxide	First Stage Oxidizer
21.	226,600	First Stage Fuel Mass (kg)
22.	2,708	First Stage Thrust (kN), Vacuum
23.	278	First Stage Specific Impulse, Vacuum
24.	205	First Stage Duration of Thrust (Sec)
25.	4 ea Solid	Booster Quantity and Type
26.	CTPB	Booster Fuel
27.	N/A	Booster Oxidizer
28.	9,500	Booster Fuel Mass (kg)
29.	650	Booster Thrust (Kn), Sea Level
30.	201	Booster Specific Impulse, Vacuum
31.	28.8	Booster Duration of Thrust (Sec)
32.	Liquid	Second Stage Propellant (Liq or Solid)
33.	UH25	Second Stage Fuel
34.	Nitrogen Tetroxide	Second Stage Oxidizer
35.	34,000	Second Stage Fuel Mass (kg)
36.	786	Second Stage Thrust (Kn), Vacuum
37.	296	Second Stage Specific Impulse, Vacuum
38.	124	Second Stage Duration of Thrust (Sec)
39.	Liquid	Third Stage Propellant (Liq or Solid)
40.	Liquid Hydrogen	Third Stage Fuel
41.	Liquid Oxygen	Third Stage Oxidizer
42.	10,450	Third Stage Fuel Mass (kg)
43.	62	Third Stage Thrust (Kn), Vacuum
44.	447	Third Stage Specific Impulse, Vacuum
45.	725	Third Stage Duration of Thrust (Sec)

Ariane 44P, Flight 1 of 2

1.	V-43	Launch Reference Number
2.	4 Apr 91	Launch Date
3.	Kourou	Launch Facility
4.	Anik E2	Payload #1 Name of Satellite
5.	2932/6465	Payload #1 Launch Weight, kg/lb
6.	1781/3927	Payload #1 On-Orbit Weight, kg/lb
7.	N/A	Payload #2 Name of Satellite
8.	N/A	Payload #2 Launch Weight, kg/lb
9.	N/A	Payload #2 On-Orbit Weight, kg/lb
10.	2932/6465	Total Payload Launch Weight, kg/lb
11.	1781/3927	Total On-Orbit Weight, kg/lb
12.	97.7%	Ratio of Launch Weight/Max Weight
13.	0.502%	Ratio of On-Orbit Wt/Takeoff Wt
14.	$12,993	Cost per Pound to GTO (Transfer Orbit)
15.	$21,390	Cost per Pound to GEO (Final Orbit)

Ariane 44P, Flight 2 of 2

1.	V-46	Launch Reference Number
2.	26 Sep 91	Launch Date
3.	Kourou	Launch Facility
4.	Anik E1	Payload #1 Name of Satellite
5.	2932/6465	Payload #1 Launch Weight, kg/lb
6.	1781/3927	Payload #1 On-Orbit Weight, kg/lb
7.	N/A	Payload #2 Name of Satellite
8.	N/A	Payload #2 Launch Weight, kg/lb
9.	N/A	Payload #2 On-Orbit Weight, kg/lb
10.	2932/6465	Total Payload Launch Weight, kg/lb
11.	1781/3927	Total On-Orbit Weight, kg/lb
12.	97.7%	Ratio of Launch Weight/Max Weight
13.	0.502%	Ratio of On-Orbit Wt/Takeoff Wt
14.	$12,993	Cost per Pound to GTO (Transfer Orbit)
15.	$21,390	Cost per Pound to GEO (Final Orbit)

ARIANE 42P (Ariane 4 with 2 solid add-on boosters)

1.	Ariane 42P	Name of Vehicle
2.	Arianespace	Manufacturing Company
3.	France	Country
4.	GTO	Orbit
5.	2400/2600/2740	Max Payload (kg) Dual/Single/H10+
6.	5292/5733/6042	Max Payload (lb) Dual/Single/H10+
7.	320,000	Takeoff Weight (kg)
8.	705,600	Takeoff Weight (lb)
9.	0.750/0.813/0.856%	Payload to Takeoff Wt Ratio Dual/S/H10+
10.	4	Number Launched to Date
11.	0	Number of Failures
12.	100%	Success Rate
13.	$68M	Cost per Flight in 1993 US Dollars
14.	$12850/11861/11255	Cost per Pound Max Load Dual/S/H10+
15.	3	Number of Stages
16.	57-59.8	Overall Length (m) Fairing Differences
17.	3.8	Diameter (m)
18.	Liquid	First Stage Propellant (Liq or Solid)
19.	UH25	First Stage Fuel
20.	Nitrogen Tetroxide	First Stage Oxidizer
21.	226,600	First Stage Fuel Mass (kg)
22.	2,708	First Stage Thrust (kN), Vacuum
23.	278	First Stage Specific Impulse, Vacuum
24.	205	First Stage Duration of Thrust (Sec)
25.	2 ea Solid	Booster Quantity and Type
26.	CTPB	Booster Fuel
27.	N/A	Booster Oxidizer
28.	9,500	Booster Fuel Mass (kg)
29.	650	Booster Thrust (Kn), Sea Level
30.	201	Booster Specific Impulse, Vacuum
31.	28.8	Booster Duration of Thrust (Sec)
32.	Liquid	Second Stage Propellant (Liq or Solid)
33.	UH25	Second Stage Fuel
34.	Nitrogen Tetroxide	Second Stage Oxidizer
35.	34,000	Second Stage Fuel Mass (kg)
36.	786	Second Stage Thrust (Kn), Vacuum
37.	296	Second Stage Specific Impulse, Vacuum
38.	124	Second Stage Duration of Thrust (Sec)
39.	Liquid	Third Stage Propellant (Liq or Solid)
40.	Liquid Hydrogen	Third Stage Fuel
41.	Liquid Oxygen	Third Stage Oxidizer
42.	10,450	Third Stage Fuel Mass (kg)
43.	62	Third Stage Thrust (Kn), Vacuum
44.	447	Third Stage Specific Impulse, Vacuum
45.	725	Third Stage Duration of Thrust (Sec)

Ariane 42P, Flight 1 of 4

1.	V-40	Launch Reference Number
2.	20 Nov 90	Launch Date
3.	Kourou	Launch Facility
4.	Satcom C1	Payload #1 Name of Satellite
5.	1169/2578	Payload #1 Launch Weight, kg/lb
6.	682/1504	Payload #1 On-Orbit Weight, kg/lb
7.	GStar 4	Payload #2 Name of Satellite
8.	1295/2855	Payload #2 Launch Weight, kg/lb
9.	741/1634	Payload #2 On-Orbit Weight, kg/lb
10.	2464/5433	Total Payload Launch Weight, kg/lb
11.	1423/3138	Total On-Orbit Weight, kg/lb
12.	102.7%	Ratio of Launch Weight/Max Weight
13.	0.445%	Ratio of On-Orbit Wt/Takeoff Wt
14.	$12,516	Cost per Pound to GTO (Transfer Orbit)
15.	$21,670	Cost per Pound to GEO (Final Orbit)

Ariane 42P, Flight 2 of 4 (Not GEO)

1.	V-52	Launch Reference Number
2.	10 Aug 92	Launch Date
3.	Kourou	Launch Facility
4.	Topex-Poseidon	Payload #1 Name of Satellite
5.	2380/5248	Payload #1 Launch Weight, kg/lb
6.	2380/5248	Payload #1 On-Orbit Weight, kg/lb
7.	N/A	Payload #2 Name of Satellite
8.	N/A	Payload #2 Launch Weight, kg/lb
9.	N/A	Payload #2 On-Orbit Weight, kg/lb
10.	2380/5248	Total Payload Launch Weight, kg/lb
11.	2380/5248	Total On-Orbit Weight, kg/lb
12.	52.8%	Ratio of Launch Weight/Max Weight
13.	0.744%	Ratio of On-Orbit Wt/Takeoff Wt
14.	$12,957	Cost per Pound to LEO (Low-Earth Orbit)

Ariane 42P+, Flight 3 of 4

1.	V-54	Launch Reference Number
2.	28 Oct 92	Launch Date
3.	Kourou	Launch Facility
4.	Galaxy 7	Payload #1 Name of Satellite
5.	2968/6544	Payload #1 Launch Weight, kg/lb
6.	1680/3704	Payload #1 On-Orbit Weight, kg/lb
7.	N/A	Payload #2 Name of Satellite
8.	N/A	Payload #2 Launch Weight, kg/lb
9.	N/A	Payload #2 On-Orbit Weight, kg/lb
10.	2968/6544	Total Payload Launch Weight, kg/lb
11.	1680/3704	Total On-Orbit Weight, kg/lb
12.	108.3%	Ratio of Launch Weight/Max Weight
13.	0.525%	Ratio of On-Orbit Wt/Takeoff Wt
14.	$10,391	Cost per Pound to GTO (Transfer Orbit)
15.	$18,359	Cost per Pound to GEO (Final Orbit)

Ariane 42P+, Flight 4 of 4

1.	V-55	Launch Reference Number
2.	1 Dec 92	Launch Date
3.	Kourou	Launch Facility
4.	Superbird A1	Payload #1 Name of Satellite
5.	2780/6130	Payload #1 Launch Weight, kg/lb
6.	1665/3671	Payload #1 On-Orbit Weight, kg/lb
7.	N/A	Payload #2 Name of Satellite
8.	N/A	Payload #2 Launch Weight, kg/lb
9.	N/A	Payload #2 On-Orbit Weight, kg/lb
10.	2780/6130	Total Payload Launch Weight, kg/lb
11.	1665/3671	Total On-Orbit Weight, kg/lb
12.	101.5%	Ratio of Launch Weight/Max Weight
13.	0.520%	Ratio of On-Orbit Wt/Takeoff Wt
14.	$11,093	Cost per Pound to GTO (Transfer Orbit)
15.	$18,524	Cost per Pound to GEO (Final Orbit)

APPENDIX C
ATLAS GEO LAUNCH VEHICLE FAMILY SUMMARIES
1988-1993

ATLAS 1

1.	Atlas 1	Name of Vehicle
2.	General Dynamics	Manufacturing Company
3.	USA	Country
4.	GTO	Orbit
5.	2375/2255	Max Payload (kg), med/lg fairing
6.	5237/4972	Max Payload (lb), med/lg fairing
7.	164,290	Takeoff Weight (kg)
8.	362,259	Takeoff Weight (lb)
9.	1.45/1.38%	Payload to Takeoff Wt Ratio, med/lg
10.	5	Number Launched to Date
11.	3	Number of Failures
12.	40%	Success Rate
13.	$63M	Cost per Flight in 1993 US Dollars
14.	$12,030/12,671	Cost per Pound Max Load, med/lg fairing
15.	$10,461/11,018	15% Handicap Cost per Pound Max Load
16.	2	Number of Stages
17.	42/43.9	Overall Length (m), med/lg fairing
18.	3.05	Diameter (m)
19.	Liquid	First Stage Propellant (Liq or Solid)
20.	RP-1	First Stage Fuel
21.	Liquid Oxygen	First Stage Oxidizer
22.	137,530	First Stage Fuel Mass (kg)
23.	1,953	First Stage Thrust (kN), Sea Level
24.	300	First Stage Specific Impulse, Vacuum
25.	156/266 Sustainer	First Stage Duration of Thrust (Sec)
26.	N/A	Booster Quantity and Type
27.	N/A	Booster Fuel
28.	N/A	Booster Oxidizer
29.	N/A	Booster Fuel Mass (kg)
30.	N/A	Booster Thrust (Kn), Vacuum
31.	N/A	Booster Specific Impulse, Vacuum
32.	N/A	Booster Duration of Thrust (Sec)
33.	Liquid	Second Stage Propellant (Liq or Solid)
34.	Liquid Hydrogen	Second Stage Fuel
35.	Liquid Oxygen	Second Stage Oxidizer
36.	13,790	Second Stage Fuel Mass (kg)
37.	146.8	Second Stage Thrust (Kn), Vacuum
38.	444	Second Stage Specific Impulse, Vacuum
39.	408 or 312+93	Second Stage Duration of Thrust (Sec)
40.	N/A	Third Stage Propellant (Liq or Solid)
41.	N/A	Third Stage Fuel
42.	N/A	Third Stage Oxidizer
43.	N/A	Third Stage Fuel Mass (kg)
44.	N/A	Third Stage Thrust (Kn), Vacuum
45.	N/A	Third Stage Specific Impulse, Vacuum
46.	N/A	Third Stage Duration of Thrust (Sec)

Atlas 1, Flight 1 of 5 (GTO Final Orbit, Not GEO)

1.	496	Launch Reference Number
2.	25 Jul 90	Launch Date
3.	ETR-36B	Launch Facility
4.	CRRES	Payload #1 Name of Satellite
5.	1724	Payload #1 Launch Weight, kg/lb
6.	1724	Payload #1 On-Orbit Weight, kg/lb
7.	75.8%	Ratio of Launch Weight/Max Weight
8.	----	Ratio of On-Orbit Wt/Takeoff Wt
9.	$16,573	Cost per Pound to GTO (Transfer Orbit)
10.	----	Cost per Pound to GEO (Final Orbit)
11.	1983/4372	15% Handicap Launch Weight, kg/lb
12.	----	15% Handicap On-Orbit Weight, kg/lb
13.	$14,410	15% Handicap GTO Cost per Pound
14.	----	15% Handicap GEO Cost per Pound

Atlas 1, Flight 2 of 5 (Failed)

1.	498	Launch Reference Number
2.	18 Apr 91	Launch Date
3.	ETR-36B	Launch Facility
4.	BS-3H	Payload #1 Name of Satellite
5.	670/1477	Payload #1 Launch Weight, kg/lb
6.	350/772	Payload #1 On-Orbit Weight, kg/lb
7.	29.7%	Ratio of Launch Weight/Max Weight
8.	0.213%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$42,654	Cost per Pound to GTO (Transfer Orbit)
10.	$81,606	Cost per Pound to GEO (Final Orbit)
11.	771/1699	15% Handicap Launch Weight, kg/lb
12.	403/888	15% Handicap On-Orbit Weight, kg/lb
13.	$37,081	15% Handicap GTO Cost per Pound
14.	$70,946	15% Handicap GEO Cost per Pound

Atlas 1, Flight 3 of 5

1.	503	Launch Reference Number
2.	14 Mar 92	Launch Date
3.	ETR-36B	Launch Facility
4.	Galaxy 5	Payload #1 Name of Satellite
5.	1412/3113	Payload #1 Launch Weight, kg/lb
6.	788/1738	Payload #1 On-Orbit Weight, kg/lb
7.	62.6%	Ratio of Launch Weight/Max Weight
8.	0.480%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$20,238	Cost per Pound to GTO (Transfer Orbit)
10.	$36,249	Cost per Pound to GEO (Final Orbit)
11.	1624/3580	15% Handicap Launch Weight, kg/lb
12.	906/1998	15% Handicap On-Orbit Weight, kg/lb
13.	$17,598	15% Handicap GTO Cost per Pound
14.	$31,532	15% Handicap GEO Cost per Pound

Atlas 1, Flight 4 of 5 (Failed)

1.	506	Launch Reference Number
2.	22 Aug 92	Launch Date
3.	ETR-36B	Launch Facility
4.	Galaxy 1R	Payload #1 Name of Satellite
5.	1200/2646	Payload #1 Launch Weight, kg/lb
6.	654/1442	Payload #1 On-Orbit Weight, kg/lb
7.	53.2%	Ratio of Launch Weight/Max Weight
8.	0.398%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$23,810	Cost per Pound to GTO (Transfer Orbit)
10.	$43,689	Cost per Pound to GEO (Final Orbit)
11.	1380/3043	15% Handicap Launch Weight, kg/lb
12.	752/1658	15% Handicap On-Orbit Weight, kg/lb
13.	$20,703	15% Handicap GTO Cost per Pound
14.	$37,998	15% Handicap GEO Cost per Pound

Atlas 1, Flight 5 of 5 (Failed)

1.	507	Launch Reference Number
2.	25 Mar 93	Launch Date
3.	ETR-36B	Launch Facility
4.	UFO #1	Payload #1 Name of Satellite
5.	2145/4731	Payload #1 Launch Weight, kg/lb
6.	1180/2602	Payload #1 On-Orbit Weight, kg/lb
7.	94.3%	Ratio of Launch Weight/Max Weight
8.	0.718%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$13,316	Cost per Pound to GTO (Transfer Orbit)
10.	$24,212	Cost per Pound to GEO (Final Orbit)
11.	2467/5439	15% Handicap Launch Weight, kg/lb
12.	1357/2992	15% Handicap On-Orbit Weight, kg/lb
13.	$11,583	15% Handicap GTO Cost per Pound
14.	$21,056	15% Handicap GEO Cost per Pound

ATLAS 2

1.	Atlas 2	Name of Vehicle
2.	General Dynamics	Manufacturing Company
3.	USA	Country
4.	GTO	Orbit
5.	2950/2810	Max Payload (kg), med/lg fairing
6.	6505/6196	Max Payload (lb), med/lg fairing
7.	187,560	Takeoff Weight (kg)
8.	413,570	Takeoff Weight (lb)
9.	1.57/1.50%	Payload to Takeoff Wt Ratio, med/lg
10.	3	Number Launched to Date
11.	0	Number of Failures
12.	100%	Success Rate
13.	$58M	Cost per Flight in 1993 US Dollars
14.	$8,916/9,361	Cost per Pound Max Load, med/lg
15.	$7,753/8,140	15% Handicap Cost per Pound Max Load
16.	2	Number of Stages
17.	46.8/47.4	Overall Length (m), med/lg fairing
18.	3.05	Diameter (m)
19.	Liquid	First Stage Propellant (Liq or Solid)
20.	RP-1	First Stage Fuel
21.	Liquid Oxygen	First Stage Oxidizer
22.	156,260	First Stage Fuel Mass (kg)
23.	2,100	First Stage Thrust (kN), Vacuum
24.	300	First Stage Specific Impulse, Vacuum
25.	169/277 Sustainer	First Stage Duration of Thrust (Sec)
26.	N/A	Booster Quantity and Type
27.	N/A	Booster Fuel
28.	N/A	Booster Oxidizer
29.	N/A	Booster Fuel Mass (kg)
30.	N/A	Booster Thrust (Kn), Vacuum
31.	N/A	Booster Specific Impulse, Vacuum
32.	N/A	Booster Duration of Thrust (Sec)
33.	Liquid	Second Stage Propellant (Liq or Solid)
34.	Liquid Hydrogen	Second Stage Fuel
35.	Liquid Oxygen	Second Stage Oxidizer
36.	16,780	Second Stage Fuel Mass (kg)
37.	146.8	Second Stage Thrust (Kn), Vacuum
38.	444	Second Stage Specific Impulse, Vacuum
39.	442	Second Stage Duration of Thrust (Sec)
40.	N/A	Third Stage Propellant (Liq or Solid)
41.	N/A	Third Stage Fuel
42.	N/A	Third Stage Oxidizer
43.	N/A	Third Stage Fuel Mass (kg)
44.	N/A	Third Stage Thrust (Kn), Vacuum
45.	N/A	Third Stage Specific Impulse, Vacuum
46.	N/A	Third Stage Duration of Thrust (Sec)

Atlas 2, Flight 1 of 3

1.	501	Launch Reference Number
2.	7 Dec 91	Launch Date
3.	ETR-36B	Launch Facility
4.	Eutelsat 2 F3	Payload #1 Name of Satellite
5.	1878/4141	Payload #1 Launch Weight, kg/lb
6.	1123/2476	Payload #1 On-Orbit Weight, kg/lb
7.	82.5%	Ratio of Launch Weight/Max Weight
8.	0.684%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$14,006	Cost per Pound to GTO (Transfer Orbit)
10.	$23,425	Cost per Pound to GEO (Final Orbit)
11.	2160/4762	15% Handicap Launch Weight, kg/lb
12.	1291/2848	15% Handicap On-Orbit Weight, kg/lb
13.	$12,179	15% Handicap GTO Cost per Pound
14.	$20,365	15% Handicap GEO Cost per Pound

Atlas 2, Flight 2 of 3

1.	502	Launch Reference Number
2.	11 Feb 92	Launch Date
3.	ETR-36B	Launch Facility
4.	DSCS 3B-1	Payload #1 Name of Satellite
5.	2564/5653	Payload #1 Launch Weight, kg/lb
6.	1040/2293	Payload #1 On-Orbit Weight, kg/lb
7.	91.2%	Ratio of Launch Weight/Max Weight
8.	0.554%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$10,260	Cost per Pound to GTO (Transfer Orbit)
10.	$25,294	Cost per Pound to GEO (Final Orbit)
11.	2949/6502	15% Handicap Launch Weight, kg/lb
12.	1196/2637	15% Handicap On-Orbit Weight, kg/lb
13.	$8,920	15% Handicap GTO Cost per Pound
14.	$21,995	15% Handicap GEO Cost per Pound

Atlas 2, Flight 3 of 3

1.	505	Launch Reference Number
2.	2 Jul 92	Launch Date
3.	ETR-36B	Launch Facility
4.	DSCS 3B-2	Payload #1 Name of Satellite
5.	2564/5653	Payload #1 Launch Weight, kg/lb
6.	1040/2293	Payload #1 On-Orbit Weight, kg/lb
7.	91.2%	Ratio of Launch Weight/Max Weight
8.	0.554%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$10,260	Cost per Pound to GTO (Transfer Orbit)
10.	$25,294	Cost per Pound to GEO (Final Orbit)
11.	2949/6502	15% Handicap Launch Weight, kg/lb
12.	1196/2637	15% Handicap On-Orbit Weight, kg/lb
13.	$8,920	15% Handicap GTO Cost per Pound
14.	$21,995	15% Handicap GEO Cost per Pound

ATLAS 2A

1.	Atlas 2A	Name of Vehicle
2.	General Dynamics	Manufacturing Company
3.	USA	Country
4.	GTO	Orbit
5.	3040/2900	Max Payload (kg), med/lg fairing
6.	6703/6395	Max Payload (lb), med/lg fairing
7.	187,560	Takeoff Weight (kg)
8.	413,570	Takeoff Weight (lb)
9.	1.62/1.55%	Payload to Takeoff Wt Ratio, med/lg
10.	1	Number Launched to Date
11.	0	Number of Failures
12.	100%	Success Rate
13.	$60M	Cost per Flight in 1993 US Dollars
14.	$8,951/9,383	Cost per Pound Max Load, med/lg
15.	$7,784/8,159	15% Handicap Cost per Pound Max Load
16.	2	Number of Stages
17.	46.8/47.4	Overall Length (m), med/lg fairing
18.	3.05	Diameter (m)
19.	Liquid	First Stage Propellant (Liq or Solid)
20.	RP-1	First Stage Fuel
21.	Liquid Oxygen	First Stage Oxidizer
22.	156,260	First Stage Fuel Mass (kg)
23.	2,100	First Stage Thrust (kN), Vacuum
24.	300	First Stage Specific Impulse, Vacuum
25.	169/277 Sustainer	First Stage Duration of Thrust (Sec)
26.	N/A	Booster Quantity and Type
27.	N/A	Booster Fuel
28.	N/A	Booster Oxidizer
29.	N/A	Booster Fuel Mass (kg)
30.	N/A	Booster Thrust (Kn), Vacuum
31.	N/A	Booster Specific Impulse, Vacuum
32.	N/A	Booster Duration of Thrust (Sec)
33.	Liquid	Second Stage Propellant (Liq or Solid)
34.	Liquid Hydrogen	Second Stage Fuel
35.	Liquid Oxygen	Second Stage Oxidizer
36.	16,780	Second Stage Fuel Mass (kg)
37.	185	Second Stage Thrust (Kn), Vac
38.	449	Second Stage Specific Impulse, Vacuum
39.	442	Second Stage Duration of Thrust (Sec)
40.	N/A	Third Stage Propellant (Liq or Solid)
41.	N/A	Third Stage Fuel
42.	N/A	Third Stage Oxidizer
43.	N/A	Third Stage Fuel Mass (kg)
44.	N/A	Third Stage Thrust (Kn), Vacuum
45.	N/A	Third Stage Specific Impulse, Vacuum
46.	N/A	Third Stage Duration of Thrust (Sec)

Atlas 2A, Flight 1 of 1

1.	504	Launch Reference Number
2.	10 Jun 92	Launch Date
3.	ETR-36B	Launch Facility
4.	Intelsat K	Payload #1 Name of Satellite
5.	2836/6253	Payload #1 Launch Weight, kg/lb
6.	1547/3411	Payload #1 On-Orbit Weight, kg/lb
7.	97.8%	Ratio of Launch Weight/Max Weight
8.	0.825%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$9,595	Cost per Pound to GTO (Transfer Orbit)
10.	$17,590	Cost per Pound to GEO (Final Orbit)
11.	3261/7191	15% Handicap Launch Weight, kg/lb
12.	1779/3923	15% Handicap On-Orbit Weight, kg/lb
13.	$8,344	15% Handicap GTO Cost per Pound
14.	$15,294	15% Handicap GEO Cost per Pound

ATLAS 2A, Block 1

1.	Atlas 2A, Blk 1	Name of Vehicle
2.	General Dynamics	Manufacturing Company
3.	USA	Country
4.	GTO	Orbit
5.	3160/3045	Max Payload (kg), med/lg fairing
6.	6968/6714	Max Payload (lb), med/lg fairing
7.	187,560	Takeoff Weight (kg)
8.	413,570	Takeoff Weight (lb)
9.	1.68/1.62%	Payload to Takeoff Wt Ratio, med/lg
10.	0	Number Launched to Date
11.	0	Number of Failures
12.	N/A	Success Rate
13.	$60M	Cost per Flight in 1993 US Dollars
14.	$8,611/8,937	Cost per Pound Max Load, med/lg
15.	$7,488/7,771	15% Handicap Cost per Pound Max Load
16.	2	Number of Stages
17.	46.8/47.4	Overall Length (m), med/lg fairing
18.	3.05	Diameter (m)
19.	Liquid	First Stage Propellant (Liq or Solid)
20.	RP-1	First Stage Fuel
21.	Liquid Oxygen	First Stage Oxidizer
22.	156,260	First Stage Fuel Mass (kg)
23.	2,100	First Stage Thrust (kN), Vacuum
24.	300	First Stage Specific Impulse, Vacuum
25.	169/277 Sustainer	First Stage Duration of Thrust (Sec)
26.	N/A	Booster Quantity and Type
27.	N/A	Booster Fuel
28.	N/A	Booster Oxidizer
29.	N/A	Booster Fuel Mass (kg)
30.	N/A	Booster Thrust (Kn), Vacuum
31.	N/A	Booster Specific Impulse, Vacuum
32.	N/A	Booster Duration of Thrust (Sec)
33.	Liquid	Second Stage Propellant (Liq or Solid)
34.	Liquid Hydrogen	Second Stage Fuel
35.	Liquid Oxygen	Second Stage Oxidizer
36.	16,780	Second Stage Fuel Mass (kg)
37.	198	Second Stage Thrust (Kn), Vac
38.	451	Second Stage Specific Impulse, Vacuum
39.	442	Second Stage Duration of Thrust (Sec)
40.	N/A	Third Stage Propellant (Liq or Solid)
41.	N/A	Third Stage Fuel
42.	N/A	Third Stage Oxidizer
43.	N/A	Third Stage Fuel Mass (kg)
44.	N/A	Third Stage Thrust (Kn), Vacuum
45.	N/A	Third Stage Specific Impulse, Vacuum
46.	N/A	Third Stage Duration of Thrust (Sec)

ATLAS 2AS

1.	Atlas 2AS	Name of Vehicle
2.	General Dynamics	Manufacturing Company
3.	USA	Country
4.	GTO	Orbit
5.	3700/3560	Max Payload (kg), med/lg fairing
6.	8159/7850	Max Payload (lb), med/lg fairing
7.	238,000	Takeoff Weight (kg)
8.	524,789	Takeoff Weight (lb)
9.	1.55/1.50%	Payload to Takeoff Wt Ratio, med/lg
10.	1	Number Launched to Date
11.	0	Number of Failures
12.	100%	Success Rate
13.	$75M	Cost per Flight in 1993 US Dollars
14.	$8,881/9,192	Cost per Pound Max Load, med/lg
15.	$7,723/7,923	15% Handicap Cost per Pound Max Load
16.	2	Number of Stages
17.	47.4	Overall Length (m)
18.	3.05	Diameter (m)
19.	Liquid	First Stage Propellant (Liq or Solid)
20.	RP-1	First Stage Fuel
21.	Liquid Oxygen	First Stage Oxidizer
22.	156,260	First Stage Fuel Mass (kg)
23.	2,100	First Stage Thrust (kN), Vacuum
24.	300	First Stage Specific Impulse, Vacuum
25.	169/277 Sustainer	First Stage Duration of Thrust (Sec)
26.	4 ea Castor 4A	Booster Quantity and Type
27.	HTPB	Booster Fuel
28.	HTPB	Booster Oxidizer
29.	10,200	Booster Fuel Mass (kg)
30.	269	Booster Thrust (Kn), Vacuum
31.	N/A	Booster Specific Impulse, Vacuum
32.	53	Booster Duration of Thrust (Sec)
33.	Liquid	Second Stage Propellant (Liq or Solid)
34.	Liquid Hydrogen	Second Stage Fuel
35.	Liquid Oxygen	Second Stage Oxidizer
36.	16,780	Second Stage Fuel Mass (kg)
37.	185	Second Stage Thrust (Kn), Vacuum
38.	449	Second Stage Specific Impulse, Vacuum
39.	442	Second Stage Duration of Thrust (Sec)
40.	N/A	Third Stage Propellant (Liq or Solid)
41.	N/A	Third Stage Fuel
42.	N/A	Third Stage Oxidizer
43.	N/A	Third Stage Fuel Mass (kg)
44.	N/A	Third Stage Thrust (Kn), Vacuum
45.	N/A	Third Stage Specific Impulse, Vacuum
46.	N/A	Third Stage Duration of Thrust (Sec)

Atlas 2AS, Flight 1 of 1

1.	1	Launch Reference Number
2.	17 Dec 93	Launch Date
3.	ETR-36	Launch Facility
4.	Telstar 401	Payload #1 Name of Satellite
5.	3100/6836	Payload #1 Launch Weight, kg/lb
6.	1705/3760	Payload #1 On-Orbit Weight, kg/lb
7.	83.8%	Ratio of Launch Weight/Max Weight
8.	0.716%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$10,971	Cost per Pound to GTO (Transfer Orbit)
10.	$19,947	Cost per Pound to GEO (Final Orbit)
11.	3565/7861	15% Handicap Launch Weight, kg/lb
12.	1961/4324	15% Handicap On-Orbit Weight, kg/lb
13.	$9,541	15% Handicap GTO Cost per Pound
14.	$17,345	15% Handicap GEO Cost per Pound

ATLAS 2AS, Block 1

1.	Atlas 2AS, Blk 1	Name of Vehicle
2.	General Dynamics	Manufacturing Company
3.	USA	Country
4.	GTO	Orbit
5.	3830/3700	Max Payload (kg), med/lg fairing
6.	8445/8159	Max Payload (lb), med/lg fairing
7.	238,000	Takeoff Weight (kg)
8.	524,789	Takeoff Weight (lb)
9.	1.61/1.55%	Payload to Takeoff Wt Ratio, med/lg
10.	0	Number Launched to Date
11.	0	Number of Failures
12.	N/A	Success Rate
13.	$75M	Cost per Flight in 1993 US Dollars
14.	$8,881/9,192	Cost per Pound Max Load, med/lg
15.	$7,723/7,993	15% Handicap Cost per Pound Max Load
16.	2	Number of Stages
17.	47.4	Overall Length (m)
18.	3.05	Diameter (m)
19.	Liquid	First Stage Propellant (Liq or Solid)
20.	RP-1	First Stage Fuel
21.	Liquid Oxygen	First Stage Oxidizer
22.	156,260	First Stage Fuel Mass (kg)
23.	2,100	First Stage Thrust (kN), Vacuum
24.	300	First Stage Specific Impulse, Vacuum
25.	169/277 Sustainer	First Stage Duration of Thrust (Sec)
26.	4 ea Castor 4A	Booster Quantity and Type
27.	HTPB	Booster Fuel
28.	HTPB	Booster Oxidizer
29.	10,200	Booster Fuel Mass (kg)
30.	269	Booster Thrust (Kn), Vacuum
31.	N/A	Booster Specific Impulse, Vacuum
32.	53	Booster Duration of Thrust (Sec)
33.	Liquid	Second Stage Propellant (Liq or Solid)
34.	Liquid Hydrogen	Second Stage Fuel
35.	Liquid Oxygen	Second Stage Oxidizer
36.	16,780	Second Stage Fuel Mass (kg)
37.	198	Second Stage Thrust (Kn), Vacuum
38.	451	Second Stage Specific Impulse, Vacuum
39.	442	Second Stage Duration of Thrust (Sec)
40.	N/A	Third Stage Propellant (Liq or Solid)
41.	N/A	Third Stage Fuel
42.	N/A	Third Stage Oxidizer
43.	N/A	Third Stage Fuel Mass (kg)
44.	N/A	Third Stage Thrust (Kn), Vacuum
45.	N/A	Third Stage Specific Impulse, Vacuum
46.	N/A	Third Stage Duration of Thrust (Sec)

APPENDIX D
CHANG ZHENG (LONG MARCH) LAUNCH VEHICLE FAMILY SUMMARIES
1988-1993

CZ-2E

1.	CZ-2E	Name of Vehicle
2.	China Great Wall	Manufacturing Company
3.	China	Country
4.	GTO	Orbit
5.	3,140	Max Payload (kg)
6.	6,924	Max Payload (lb)
7.	462,000	Takeoff Weight (kg)
8.	1,018,710	Takeoff Weight (lb)
9.	0.680%	Payload to Takeoff Wt Ratio
10.	3	Number Launched to Date
11.	1	Number of Failures
12.	67%	Success Rate
13.	$44M	Cost per Flight in 1993 US Dollars
14.	$6,354	Cost per Pound Max Load
15.	$5,526	15% Handicap Cost per Pound Max Load
16.	3	Number of Stages
17.	51.2	Overall Length (m)
18.	3.35	Diameter (m)
19.	Liquid	First Stage Propellant (Liq or Solid)
20.	UDMH	First Stage Fuel
21.	Nitrogen Tetroxide	First Stage Oxidizer
22.	187,000	First Stage Fuel Mass (kg)
23.	2,961	First Stage Thrust (kN), Sea Level
24.	261	First Stage Specific Impulse, Vacuum
25.	159	First Stage Duration of Thrust (Sec)
26.	4 ea Liquid	Booster Quantity and Type
27.	UDMH	Booster Fuel
28.	Nitrogen Tetroxide	Booster Oxidizer
29.	38,000	Booster Fuel Mass (kg)
30.	740.35	Booster Thrust (Kn), Vacuum
31.	261	Booster Specific Impulse, Vacuum
32.	126	Booster Duration of Thrust (Sec)
33.	Liquid	Second Stage Propellant (Liq or Solid)
34.	UDMH	Second Stage Fuel
35.	Nitrogen Tetroxide	Second Stage Oxidizer
36.	86,000	Second Stage Fuel Mass (kg)
37.	788.4	Second Stage Thrust (Kn), Vacuum
38.	298	Second Stage Specific Impulse, Vacuum
39.	300/413 Vernier	Second Stage Duration of Thrust (Sec)
40.	N/A	Third Stage Propellant (Liq or Solid)
41.	N/A	Third Stage Fuel
42.	N/A	Third Stage Oxidizer
43.	N/A	Third Stage Fuel Mass (kg)
44.	N/A	Third Stage Thrust (Kn), Vacuum
45.	N/A	Third Stage Specific Impulse, Vacuum
46.	N/A	Third Stage Duration of Thrust (Sec)

CZ-2E, Flight 1 of 3 (Not GEO)

1.	31	Launch Reference Number
2.	16 Jul 90	Launch Date
3.	Xichang	Launch Facility
4.	Test + Badr 1	Payload #1 Name of Satellite
5.	----	Payload #1 Launch Weight, kg/lb
6.	----	Payload #1 On-Orbit Weight, kg/lb
7.	----	Ratio of Launch Weight/Max Weight
8.	----	Ratio of On-Orbit Wt/Takeoff Wt
9.	----	Cost per Pound to GTO (Transfer Orbit)
10.	----	Cost per Pound to GEO (Final Orbit)
11.	----	15% Handicap Launch Weight, kg/lb
12.	----	15% Handicap On-Orbit Weight, kg/lb
13.	----	15% Handicap GTO Cost per Pound
14.	----	15% Handicap GEO Cost per Pound

CZ-2E, Flight 2 of 3

1.	36	Launch Reference Number
2.	13 Aug 92	Launch Date
3.	Xichang	Launch Facility
4.	Optus B1	Payload #1 Name of Satellite
5.	3164/6977	Payload #1 Launch Weight, kg/lb
6.	1582/3488	Payload #1 On-Orbit Weight, kg/lb
7.	100.7%	Ratio of Launch Weight/Max Weight
8.	0.685	Ratio of On-Orbit Wt/Takeoff Wt
9.	$6,306	Cost per Pound to GTO (Transfer Orbit)
10.	$12,615	Cost per Pound to GEO (Final Orbit)
11.	3639/8023	15% Handicap Launch Weight, kg/lb
12.	1819/4012	15% Handicap On-Orbit Weight, kg/lb
13.	$5,484	15% Handicap GTO Cost per Pound
14.	$10,967	15% Handicap GEO Cost per Pound

CZ-2E, Flight 3 of 3 (Failed)

1.	38	Launch Reference Number
2.	21 Dec 92	Launch Date
3.	Xichang	Launch Facility
4.	Optus B2	Payload #1 Name of Satellite
5.	3164/6977	Payload #1 Launch Weight, kg/lb
6.	1582/3488	Payload #1 On-Orbit Weight, kg/lb
7.	100.7%	Ratio of Launch Weight/Max Weight
8.	0.685	Ratio of On-Orbit Wt/Takeoff Wt
9.	$6,306	Cost per Pound to GTO (Transfer Orbit)
10.	$12,615	Cost per Pound to GEO (Final Orbit)
11.	3639/8023	15% Handicap Launch Weight, kg/lb
12.	1819/4012	15% Handicap On-Orbit Weight, kg/lb
13.	$5,484	15% Handicap GTO Cost per Pound
14.	$10,967	15% Handicap GEO Cost per Pound

CZ-3

1.	CZ-3	Name of Vehicle
2.	China Great Wall	Manufacturing Company
3.	China	Country
4.	GTO	Orbit
5.	1,340	Max Payload (kg)
6.	2,955	Max Payload (lb)
7.	204,000	Takeoff Weight (kg)
8.	449,820	Takeoff Weight (lb)
9.	0.657%	Payload to Takeoff Wt Ratio
10.	8	Number Launched to Date
11.	2	Number of Failures
12.	75%	Success Rate
13.	$38M	Cost per Flight in 1993 US Dollars
14.	$12,860	Cost per Pound Max Load
15.	$11,182	15% Handicap Cost per Pound Max Load
16.	3	Number of Stages
17.	43.85	Overall Length (m)
18.	3.35	Diameter (m)
19.	Liquid	First Stage Propellant (Liq or Solid)
20.	UDMH	First Stage Fuel
21.	Nitrogen Tetroxide	First Stage Oxidizer
22.	142,000	First Stage Fuel Mass (kg)
23.	2,785	First Stage Thrust (kN), Sea Level
24.	264	First Stage Specific Impulse, Vacuum
25.	132	First Stage Duration of Thrust (Sec)
26.	N/A	Booster Quantity and Type
27.	N/A	Booster Fuel
28.	N/A	Booster Oxidizer
29.	N/A	Booster Fuel Mass (kg)
30.	N/A	Booster Thrust (Kn), Vacuum
31.	N/A	Booster Specific Impulse, Vacuum
32.	N/A	Booster Duration of Thrust (Sec)
33.	Liquid	Second Stage Propellant (Liq or Solid)
34.	UDMH	Second Stage Fuel
35.	Nitrogen Tetroxide	Second Stage Oxidizer
36.	35,000	Second Stage Fuel Mass (kg)
37.	765.85	Second Stage Thrust (Kn), Vacuum
38.	298	Second Stage Specific Impulse, Vacuum
39.	110/190 Vernier	Second Stage Duration of Thrust (Sec)
40.	Liquid	Third Stage Propellant (Liq or Solid)
41.	Liquid Hydrogen	Third Stage Fuel
42.	Liquid Oxygen	Third Stage Oxidizer
43.	8,500	Third Stage Fuel Mass (kg)
44.	44.147	Third Stage Thrust (Kn), Vacuum
45.	420	Third Stage Specific Impulse, Vacuum
46.	500 + 300	Third Stage Duration of Thrust (Sec)

CZ-3, Flight 1 of 8 (Failed)

1.	17	Launch Reference Number
2.	29 Jan 84	Launch Date
3.	Xichang	Launch Facility
4.	STTW-T1	Payload #1 Name of Satellite
5.	900/1945	Payload #1 Launch Weight, kg/lb
6.	420/926	Payload #1 On-Orbit Weight, kg/lb
7.	67.2%	Ratio of Launch Weight/Max Weight
8.	0.206	Ratio of On-Orbit Wt/Takeoff Wt
9.	$19,023	Cost per Pound to GTO (Transfer Orbit)
10.	$39,957	Cost per Pound to GEO (Final Orbit)
11.	1035/2282	15% Handicap Launch Weight, kg/lb
12.	483/1065	15% Handicap On-Orbit Weight, kg/lb
13.	$16,214	15% Handicap GTO Cost per Pound
14.	$34,742	15% Handicap GEO Cost per Pound

CZ-3, Flight 2 of 8

1.	18	Launch Reference Number
2.	8 Apr 84	Launch Date
3.	Xichang	Launch Facility
4.	STTW-T2	Payload #1 Name of Satellite
5.	900/1945	Payload #1 Launch Weight, kg/lb
6.	420/926	Payload #1 On-Orbit Weight, kg/lb
7.	67.2%	Ratio of Launch Weight/Max Weight
8.	0.206	Ratio of On-Orbit Wt/Takeoff Wt
9.	$19,023	Cost per Pound to GTO (Transfer Orbit)
10.	$39,957	Cost per Pound to GEO (Final Orbit)
11.	1035/2282	15% Handicap Launch Weight, kg/lb
12.	483/1065	15% Handicap On-Orbit Weight, kg/lb
13.	$16,214	15% Handicap GTO Cost per Pound
14.	$34,742	15% Handicap GEO Cost per Pound

CZ-3, Flight 3 of 8

1.	21	Launch Reference Number
2.	1 Feb 86	Launch Date
3.	Xichang	Launch Facility
4.	STTW-1	Payload #1 Name of Satellite
5.	1024/2258	Payload #1 Launch Weight, kg/lb
6.	450/992	Payload #1 On-Orbit Weight, kg/lb
7.	76.4%	Ratio of Launch Weight/Max Weight
8.	0.221%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$16,386	Cost per Pound to GTO (Transfer Orbit)
10.	$37,298	Cost per Pound to GEO (Final Orbit)
11.	1178/2597	15% Handicap Launch Weight, kg/lb
12.	518/1141	15% Handicap On-Orbit Weight, kg/lb
13.	$14,247	15% Handicap GTO Cost per Pound
14.	$32,428	15% Handicap GEO Cost per Pound

CZ-3, Flight 4 of 8

1.	25	Launch Reference Number
2.	7 Mar 88	Launch Date
3.	Xichang	Launch Facility
4.	STTW-2	Payload #1 Name of Satellite
5.	1024/2258	Payload #1 Launch Weight, kg/lb
6.	450/992	Payload #1 On-Orbit Weight, kg/lb
7.	76.4%	Ratio of Launch Weight/Max Weight
8.	0.221%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$16,386	Cost per Pound to GTO (Transfer Orbit)
10.	$37,298	Cost per Pound to GEO (Final Orbit)
11.	1178/2597	15% Handicap Launch Weight, kg/lb
12.	518/1141	15% Handicap On-Orbit Weight, kg/lb
13.	$14,247	15% Handicap GTO Cost per Pound
14.	$32,428	15% Handicap GEO Cost per Pound

CZ-3, Flight 5 of 8

1.	28	Launch Reference Number
2.	22 Dec 88	Launch Date
3.	Xichang	Launch Facility
4.	STTW-3	Payload #1 Name of Satellite
5.	1024/2258	Payload #1 Launch Weight, kg/lb
6.	450/992	Payload #1 On-Orbit Weight, kg/lb
7.	76.4%	Ratio of Launch Weight/Max Weight
8.	0.221%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$16,386	Cost per Pound to GTO (Transfer Orbit)
10.	$37,298	Cost per Pound to GEO (Final Orbit)
11.	1178/2597	15% Handicap Launch Weight, kg/lb
12.	518/1141	15% Handicap On-Orbit Weight, kg/lb
13.	$14,247	15% Handicap GTO Cost per Pound
14.	$32,428	15% Handicap GEO Cost per Pound

CZ-3, Flight 6 of 8

1.	29	Launch Reference Number
2.	4 Feb 90	Launch Date
3.	Xichang	Launch Facility
4.	STTW-4	Payload #1 Name of Satellite
5.	1024/2258	Payload #1 Launch Weight, kg/lb
6.	450/992	Payload #1 On-Orbit Weight, kg/lb
7.	76.4%	Ratio of Launch Weight/Max Weight
8.	0.221%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$16,386	Cost per Pound to GTO (Transfer Orbit)
10.	$37,298	Cost per Pound to GEO (Final Orbit)
11.	1178/2597	15% Handicap Launch Weight, kg/lb
12.	518/1141	15% Handicap On-Orbit Weight, kg/lb
13.	$14,247	15% Handicap GTO Cost per Pound
14.	$32,428	15% Handicap GEO Cost per Pound

CZ-3, Flight 7 of 8

1.	30	Launch Reference Number
2.	8 Apr 90	Launch Date
3.	Xichang	Launch Facility
4.	Asiasat 1	Payload #1 Name of Satellite
5.	1244/2743	Payload #1 Launch Weight, kg/lb
6.	620/1367	Payload #1 On-Orbit Weight, kg/lb
7.	92.8%	Ratio of Launch Weight/Max Weight
8.	0.304%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$13,489	Cost per Pound to GTO (Transfer Orbit)
10.	$27,067	Cost per Pound to GEO (Final Orbit)
11.	1431/3154	15% Handicap Launch Weight, kg/lb
12.	713/1572	15% Handicap On-Orbit Weight, kg/lb
13.	$11,731	15% Handicap GTO Cost per Pound
14.	$23,537	15% Handicap GEO Cost per Pound

CZ-3, Flight 8 of 8 (Failed)

1.	34	Launch Reference Number
2.	28 Dec 91	Launch Date
3.	Xichang	Launch Facility
4.	STTW	Payload #1 Name of Satellite
5.	1024/2258	Payload #1 Launch Weight, kg/lb
6.	450/992	Payload #1 On-Orbit Weight, kg/lb
7.	76.4%	Ratio of Launch Weight/Max Weight
8.	0.221%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$16,386	Cost per Pound to GTO (Transfer Orbit)
10.	$37,298	Cost per Pound to GEO (Final Orbit)
11.	1178/2597	15% Handicap Launch Weight, kg/lb
12.	518/1141	15% Handicap On-Orbit Weight, kg/lb
13.	$14,247	15% Handicap GTO Cost per Pound
14.	$32,428	15% Handicap GEO Cost per Pound

APPENDIX E
DELTA GEO LAUNCH VEHICLE FAMILY SUMMARIES
1988-1993

DELTA II 6925

1.	Delta II 6925	Name of Vehicle
2.	McDonnell Douglas	Manufacturing Company
3.	USA	Country
4.	GTO	Orbit
5.	1447	Max Payload (kg)
6.	3191	Max Payload (lb)
7.	217,640	Takeoff Weight (kg)
8.	479,896	Takeoff Weight (lb)
9.	0.665%	Payload to Takeoff Wt Ratio
10.	17	Number Launched to Date
11.	0	Number of Failures
12.	100%	Success Rate
13.	$43M/58M	Cost per Flight in 1993 $US, Mil/Civ
14.	$13,475/$18,176	Cost per Pound Max Load, Mil/Civ
15.	$11,718/$15,805	15% Handicap Cost/lb Max Load, Mil/Civ
16.	3	Number of Stages
17.	38.41	Overall Length (m)
18.	2.44	Diameter (m)
19.	Liquid	First Stage Propellant (Liq or Solid)
20.	RP-1	First Stage Fuel
21.	Liquid Oxygen	First Stage Oxidizer
22.	95,776	First Stage Fuel Mass (kg)
23.	920.7	First Stage Thrust (kN), Sea Level
24.	302	First Stage Specific Impulse, Vacuum
25.	265	First Stage Duration of Thrust (Sec)
26.	9 ea Solid	Booster Quantity and Type
27.	HTPB	Booster Fuel
28.	HTPB	Booster Oxidizer
29.	10,121	Booster Fuel Mass (kg)
30.	483.5	Booster Thrust (Kn), Vacuum
31.	269	Booster Specific Impulse, Sea Level
32.	56.2	Booster Duration of Thrust (Sec)
33.	Liquid	Second Stage Propellant (Liq or Solid)
34.	Aerozine-50	Second Stage Fuel
35.	Nitrogen Tetroxide	Second Stage Oxidizer
36.	6,063	Second Stage Fuel Mass (kg)
37.	42.9	Second Stage Thrust (Kn), Vacuum
38.	317	Second Stage Specific Impulse, Vacuum
39.	440	Second Stage Duration of Thrust (Sec)
40.	Solid	Third Stage Propellant (Liq or Solid)
41.	HTPB	Third Stage Fuel
42.	HTPB	Third Stage Oxidizer
43.	1,756-2,025	Third Stage Fuel Mass (kg)
44.	67.16	Third Stage Thrust (Kn), Vacuum
45.	286	Third Stage Specific Impulse, Vacuum
46.	88.1	Third Stage Duration of Thrust (Sec)

Delta II 6925, Flight 1 of 17 (20,000km Final Orbit, Not GEO)

1.	184	Launch Reference Number
2.	14 Feb 89	Launch Date
3.	ETR-17A	Launch Facility
4.	Navstar 2-1	Payload #1 Name of Satellite
5.	1667/3676	Payload #1 Launch Weight, kg/lb
6.	843/1859	Payload #1 On-Orbit Weight, kg/lb
7.	Max Weight Unknown	Ratio of Launch Weight/Max Weight
8.	0.387%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$11,697	Cost per Pound to Orbit (Not GTO)
10.	$23,131	Cost per Pound to Final Circular Orbit
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

Delta II 6925, Flight 2 of 17 (20,000km Final Orbit, Not GEO)

1.	185	Launch Reference Number
2.	10 Jun 89	Launch Date
3.	ETR-17A	Launch Facility
4.	Navstar 2-2	Payload #1 Name of Satellite
5.	1667/3676	Payload #1 Launch Weight, kg/lb
6.	843/1859	Payload #1 On-Orbit Weight, kg/lb
7.	Max Weight Unknown	Ratio of Launch Weight/Max Weight
8.	0.387%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$11,697	Cost per Pound to Orbit (Not GTO)
10.	$23,131	Cost per Pound to Final Circular Orbit
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

Delta II 6925, Flight 3 of 17 (20,000km Final Orbit, Not GEO)

1.	186	Launch Reference Number
2.	18 Aug 89	Launch Date
3.	ETR-17A	Launch Facility
4.	Navstar 2-3	Payload #1 Name of Satellite
5.	1667/3676	Payload #1 Launch Weight, kg/lb
6.	843/1859	Payload #1 On-Orbit Weight, kg/lb
7.	Max Weight Unknown	Ratio of Launch Weight/Max Weight
8.	0.387%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$11,697	Cost per Pound to Orbit (Not GTO)
10.	$23,131	Cost per Pound to Final Circular Orbit
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

Delta II 6925, Flight 4 of 17 (20,000km Final Orbit, Not GEO)

1.	188	Launch Reference Number
2.	21 Oct 89	Launch Date
3.	ETR-17A	Launch Facility
4.	Navstar 2-4	Payload #1 Name of Satellite
5.	1667/3676	Payload #1 Launch Weight, kg/lb
6.	843/1859	Payload #1 On-Orbit Weight, kg/lb
7.	Max Weight Unknown	Ratio of Launch Weight/Max Weight
8.	0.387%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$11,697	Cost per Pound to Orbit (Not GTO)
10.	$23,131	Cost per Pound to Final Circular Orbit
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

Delta II 6925, Flight 5 of 17 (20,000km Final Orbit, Not GEO)

1.	190	Launch Reference Number
2.	11 Dec 89	Launch Date
3.	ETR-17B	Launch Facility
4.	Navstar 2-5	Payload #1 Name of Satellite
5.	1667/3676	Payload #1 Launch Weight, kg/lb
6.	843/1859	Payload #1 On-Orbit Weight, kg/lb
7.	Max Weight Unknown	Ratio of Launch Weight/Max Weight
8.	0.387%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$11,697	Cost per Pound to Orbit (Not GTO)
10.	$23,131	Cost per Pound to Final Circular Orbit
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

Delta II 6925, Flight 6 of 17 (20,000km Final Orbit, Not GEO)

1.	191	Launch Reference Number
2.	24 Jan 90	Launch Date
3.	ETR-17A	Launch Facility
4.	Navstar 2-6	Payload #1 Name of Satellite
5.	1667/3676	Payload #1 Launch Weight, kg/lb
6.	843/1859	Payload #1 On-Orbit Weight, kg/lb
7.	Max Weight Unknown	Ratio of Launch Weight/Max Weight
8.	0.387%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$11,697	Cost per Pound to Orbit (Not GTO)
10.	$23,131	Cost per Pound to Final Circular Orbit
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

Delta II 6920-8, Flight 7 of 17 (540km Final Orbit, Not GEO)

1.	192	Launch Reference Number
2.	14 Feb 90	Launch Date
3.	ETR-17B	Launch Facility
4.	RME/LACE	Payload #1 Name of Satellite
5.	----	Payload #1 Launch Weight, kg/lb
6.	----	Payload #1 On-Orbit Weight, kg/lb
7.	----	Ratio of Launch Weight/Max Weight
8.	----	Ratio of On-Orbit Wt/Takeoff Wt
9.	----	Cost per Pound to Orbit (Not GTO)
10.	----	Cost per Pound to Final Circular Orbit
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

Delta II 6925, Flight 8 of 17 (20,000km Final Orbit, Not GEO)

1.	193	Launch Reference Number
2.	26 Mar 90	Launch Date
3.	ETR-17A	Launch Facility
4.	Navstar 2-7	Payload #1 Name of Satellite
5.	1667/3676	Payload #1 Launch Weight, kg/lb
6.	843/1859	Payload #1 On-Orbit Weight, kg/lb
7.	Max Weight Unknown	Ratio of Launch Weight/Max Weight
8.	0.387%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$11,697	Cost per Pound to Orbit (Not GTO)
10.	$23,131	Cost per Pound to Final Circular Orbit
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

Delta II 6925, Flight 9 of 17

1.	194	Launch Reference Number
2.	13 Apr 90	Launch Date
3.	ETR-17B	Launch Facility
4.	Palapa B2R	Payload #1 Name of Satellite
5.	1240/2734	Payload #1 Launch Weight, kg/lb
6.	652/1438	Payload #1 On-Orbit Weight, kg/lb
7.	85.7%	Ratio of Launch Weight/Max Weight
8.	0.570%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$21,214	Cost per Pound to GTO
10.	$40,334	Cost per Pound to GEO
11.	1426/3144	15% Handicap Launch Weight, kg/lb
12.	750/1653	15% Handicap On-Orbit Weight, kg/lb
13.	$18,448	15% Handicap GTO Cost per Pound
14.	$35,088	15% Handicap GEO Cost per Pound

Delta II 6920-10, Flight 10 of 17 (580km Circular, Not GEO)

1.	195	Launch Reference Number
2.	1 Jun 90	Launch Date
3.	ETR-17A	Launch Facility
4.	Rosat	Payload #1 Name of Satellite
5.	2462/5429	Payload #1 Launch Weight, kg/lb
6.	1555/3429	Payload #1 On-Orbit Weight, kg/lb
7.	----	Ratio of Launch Weight/Max Weight
8.	----	Ratio of On-Orbit Wt/Takeoff Wt
9.	----	Cost per Pound to Orbit (Not GTO)
10.	----	Cost per Pound to Final Circular Orbit
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

Delta II 6925, Flight 11 of 17 (20,000km Final Orbit, Not GEO)

1.	197	Launch Reference Number
2.	2 Aug 90	Launch Date
3.	ETR-17B	Launch Facility
4.	Navstar 2-8	Payload #1 Name of Satellite
5.	1667/3676	Payload #1 Launch Weight, kg/lb
6.	843/1859	Payload #1 On-Orbit Weight, kg/lb
7.	Max Weight Unknown	Ratio of Launch Weight/Max Weight
8.	0.387%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$11,697	Cost per Pound to Orbit (Not GTO)
10.	$23,131	Cost per Pound to Final Circular Orbit
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

Delta II 6925, Flight 12 of 17

1.	198	Launch Reference Number
2.	18 Aug 90	Launch Date
3.	ETR-17B	Launch Facility
4.	Marcopolo 2	Payload #1 Name of Satellite
5.	1250/2756	Payload #1 Launch Weight, kg/lb
6.	660/1455	Payload #1 On-Orbit Weight, kg/lb
7.	86.4%	Ratio of Launch Weight/Max Weight
8.	0.303%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$21,045	Cost per Pound to GTO
10.	$39,863	Cost per Pound to GEO
11.	1438/3170	15% Handicap Launch Weight, kg/lb
12.	759/1674	15% Handicap On-Orbit Weight, kg/lb
13.	$18,297	15% Handicap GTO Cost per Pound
14.	$34,648	15% Handicap GEO Cost per Pound

Delta II 6925, Flight 13 of 17 (20,000km Final Orbit, Not GEO)

1.	199	Launch Reference Number
2.	1 Oct 90	Launch Date
3.	ETR-17A	Launch Facility
4.	Navstar 2-9	Payload #1 Name of Satellite
5.	1667/3676	Payload #1 Launch Weight, kg/lb
6.	843/1859	Payload #1 On-Orbit Weight, kg/lb
7.	Max Weight Unknown	Ratio of Launch Weight/Max Weight
8.	0.387%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$11,697	Cost per Pound to Orbit (Not GTO)
10.	$23,131	Cost per Pound to Final Circular Orbit
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

Delta II 6925, Flight 14 of 17

1.	200	Launch Reference Number
2.	30 Oct 90	Launch Date
3.	ETR-17B	Launch Facility
4.	Inmarsat 2 F1	Payload #1 Name of Satellite
5.	1385/3054	Payload #1 Launch Weight, kg/lb
6.	690/1521	Payload #1 On-Orbit Weight, kg/lb
7.	95.7%	Ratio of Launch Weight/Max Weight
8.	0.317%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$18,991	Cost per Pound to GTO
10.	$38,133	Cost per Pound to GEO
11.	1593/3512	15% Handicap Launch Weight, kg/lb
12.	794/1750	15% Handicap On-Orbit Weight, kg/lb
13.	$16,515	15% Handicap GTO Cost per Pound
14.	$33,143	15% Handicap GEO Cost per Pound

Delta II 6925, Flight 15 of 17

1.	203	Launch Reference Number
2.	8 Mar 91	Launch Date
3.	ETR-17B	Launch Facility
4.	Inmarsat 2 F2	Payload #1 Name of Satellite
5.	1385/3054	Payload #1 Launch Weight, kg/lb
6.	690/1521	Payload #1 On-Orbit Weight, kg/lb
7.	95.7%	Ratio of Launch Weight/Max Weight
8.	0.317%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$18,991	Cost per Pound to GTO
10.	$38,133	Cost per Pound to GEO
11.	1593/3512	15% Handicap Launch Weight, kg/lb
12.	794/1750	15% Handicap On-Orbit Weight, kg/lb
13.	$16,515	15% Handicap GTO Cost per Pound
14.	$33,143	15% Handicap GEO Cost per Pound

Delta II 6925, Flight 16 of 17 (514km Circular, Not GEO)

1.	210	Launch Reference Number
2.	7 Jun 92	Launch Date
3.	ETR-17A	Launch Facility
4.	EUVE UV Telescope	Payload #1 Name of Satellite
5.	3256/7179	Payload #1 Launch Weight, kg/lb
6.	3256/7179	Payload #1 On-Orbit Weight, kg/lb
7.	----	Ratio of Launch Weight/Max Weight
8.	----	Ratio of On-Orbit Wt/Takeoff Wt
9.	----	Cost per Pound to Orbit (Not GTO)
10.	----	Cost per Pound to Final Circular Orbit
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

Delta II 6925, Flight 17 of 17 (Sun Synch Moon, Not GEO)

1.	212	Launch Reference Number
2.	24 Jul 92	Launch Date
3.	ETR-17A	Launch Facility
4.	Geotail-Japan	Payload #1 Name of Satellite
5.	1009/2225	Payload #1 Launch Weight, kg/lb
6.	----	Payload #1 On-Orbit Weight, kg/lb
7.	----	Ratio of Launch Weight/Max Weight
8.	----	Ratio of On-Orbit Wt/Takeoff Wt
9.	----	Cost per Pound to GTO
10.	----	Cost per Pound to GEO
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

DELTA II 7925

1.	Delta II 7925	Name of Vehicle
2.	McDonnell Douglas	Manufacturing Company
3.	USA	Country
4.	GTO	Orbit
5.	1819	Max Payload (kg)
6.	4011	Max Payload (lb)
7.	229,730	Takeoff Weight (kg)
8.	506,555	Takeoff Weight (lb)
9.	0.792%	Payload to Takeoff Wt Ratio
10.	16	Number Launched to Date
11.	0	Number of Failures
12.	100%	Success Rate
13.	$43M/58M	Cost per Flight in 1993 $US, Mil/Civ
14.	$10,721/$14,460	Cost per Pound Max Load, Mil/Civ
15.	$9,322/$12,574	15% Handicap Cost/lb Max Load, Mil/Civ
16.	3	Number of Stages
17.	38.41	Overall Length (m)
18.	2.44	Diameter (m)
19.	Liquid	First Stage Propellant (Liq or Solid)
20.	RP-1	First Stage Fuel
21.	Liquid Oxygen	First Stage Oxidizer
22.	95,776	First Stage Fuel Mass (kg)
23.	1,054	First Stage Thrust (kN), Sea Level
24.	297	First Stage Specific Impulse, Vacuum
25.	265	First Stage Duration of Thrust (Sec)
26.	9 ea Solid	Booster Quantity and Type
27.	HTPB	Booster Fuel
28.	HTPB	Booster Oxidizer
29.	11,703	Booster Fuel Mass (kg)
30.	493	Booster Thrust (Kn), Vacuum
31.	273	Booster Specific Impulse, Vacuum
32.	63.7	Booster Duration of Thrust (Sec)
33.	Liquid	Second Stage Propellant (Liq or Solid)
34.	Aerozine-50	Second Stage Fuel
35.	Nitrogen Tetroxide	Second Stage Oxidizer
36.	6,063	Second Stage Fuel Mass (kg)
37.	42.9	Second Stage Thrust (Kn), Vacuum
38.	317	Second Stage Specific Impulse, Vacuum
39.	349	Second Stage Duration of Thrust (Sec)
40.	Solid	Third Stage Propellant (Liq or Solid)
41.	HTPB	Third Stage Fuel
42.	HTPB	Third Stage Oxidizer
43.	1,756-2,025	Third Stage Fuel Mass (kg)
44.	66	Third Stage Thrust (Kn), Vacuum
45.	286	Third Stage Specific Impulse, Vacuum
46.	84	Third Stage Duration of Thrust (Sec)

Delta II 7925, Flight 1 of 16 (20,000km Final Orbit, Not GEO)

1.	201	Launch Reference Number
2.	26 Nov 90	Launch Date
3.	ETR-17A	Launch Facility
4.	Navstar 2-10	Payload #1 Name of Satellite
5.	1881/4148	Payload #1 Launch Weight, kg/lb
6.	930/2051	Payload #1 On-Orbit Weight, kg/lb
7.	Max Weight Unknown	Ratio of Launch Weight/Max Weight
8.	0.405%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$10,366	Cost per Pound to Orbit (Not GTO)
10.	$20,965	Cost per Pound to Final Circular Orbit
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

Delta II 7925, Flight 2 of 16

1.	202	Launch Reference Number
2.	8 Jan 91	Launch Date
3.	ETR-17A	Launch Facility
4.	Nato 4A	Payload #1 Name of Satellite
5.	1433/3160	Payload #1 Launch Weight, kg/lb
6.	790/1742	Payload #1 On-Orbit Weight, kg/lb
7.	78.8%	Ratio of Launch Weight/Max Weight
8.	0.344%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$18,354	Cost per Pound to Orbit (Not GTO)
10.	$33,295	Cost per Pound to Final Circular Orbit
11.	1648/3634	15% Handicap Launch Weight, kg/lb
12.	909/2003	15% Handicap On-Orbit Weight, kg/lb
13.	$15,960	15% Handicap GTO Cost per Pound
14.	$28,957	15% Handicap GEO Cost per Pound

Delta II 7925, Flight 3 of 16

1.	204	Launch Reference Number
2.	13 Apr 91	Launch Date
3.	ETR-17B	Launch Facility
4.	ASC 2	Payload #1 Name of Satellite
5.	1272/2805	Payload #1 Launch Weight, kg/lb
6.	728/1605	Payload #1 On-Orbit Weight, kg/lb
7.	69.9%	Ratio of Launch Weight/Max Weight
8.	0.317%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$20,677	Cost per Pound to Orbit (Not GTO)
10.	$36,137	Cost per Pound to Final Circular Orbit
11.	1463/3225	15% Handicap Launch Weight, kg/lb
12.	837/1846	15% Handicap On-Orbit Weight, kg/lb
13.	$17,984	15% Handicap GTO Cost per Pound
14.	$31,419	15% Handicap GEO Cost per Pound

Delta II 7925, Flight 4 of 16

1.	205	Launch Reference Number
2.	29 May 91	Launch Date
3.	ETR-17B	Launch Facility
4.	Aurora 2	Payload #1 Name of Satellite
5.	1338/2950	Payload #1 Launch Weight, kg/lb
6.	736/1623	Payload #1 On-Orbit Weight, kg/lb
7.	73.6%	Ratio of Launch Weight/Max Weight
8.	0.320%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$19,661	Cost per Pound to Orbit (Not GTO)
10.	$35,736	Cost per Pound to Final Circular Orbit
11.	1539/3393	15% Handicap Launch Weight, kg/lb
12.	846/1866	15% Handicap On-Orbit Weight, kg/lb
13.	$17,094	15% Handicap GTO Cost per Pound
14.	$31,082	15% Handicap GEO Cost per Pound

Delta II 7925, Flight 5 of 16 (20,000km Final Orbit, Not GEO)

1.	206	Launch Reference Number
2.	4 Jul 91	Launch Date
3.	ETR-17A	Launch Facility
4.	Navstar 2-11	Payload #1 Name of Satellite
5.	1881/4148	Payload #1 Launch Weight, kg/lb
6.	930/2051	Payload #1 On-Orbit Weight, kg/lb
7.	Max Weight Unknown	Ratio of Launch Weight/Max Weight
8.	0.405%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$10,366	Cost per Pound to Orbit (Not GTO)
10.	$20,965	Cost per Pound to Final Circular Orbit
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

Delta II 7925, Flight 6 of 16 (20,000km Final Orbit, Not GEO)

1.	207	Launch Reference Number
2.	23 Feb 92	Launch Date
3.	ETR-17B	Launch Facility
4.	Navstar 2-12	Payload #1 Name of Satellite
5.	1881/4148	Payload #1 Launch Weight, kg/lb
6.	930/2051	Payload #1 On-Orbit Weight, kg/lb
7.	Max Weight Unknown	Ratio of Launch Weight/Max Weight
8.	0.405%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$10,366	Cost per Pound to Orbit (Not GTO)
10.	$20,965	Cost per Pound to Final Circular Orbit
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

Delta II 7925, Flight 7 of 16 (20,000km Final Orbit, Not GEO)

1.	208	Launch Reference Number
2.	10 Apr 92	Launch Date
3.	ETR-17B	Launch Facility
4.	Navstar 2-13	Payload #1 Name of Satellite
5.	1881/4148	Payload #1 Launch Weight, kg/lb
6.	930/2051	Payload #1 On-Orbit Weight, kg/lb
7.	Max Weight Unknown	Ratio of Launch Weight/Max Weight
8.	0.405%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$10,366	Cost per Pound to Orbit (Not GTO)
10.	$20,965	Cost per Pound to Final Circular Orbit
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

Delta II 7925, Flight 8 of 16

1.	209	Launch Reference Number
2.	14 May 92	Launch Date
3.	ETR-17B	Launch Facility
4.	Palapa B4	Payload #1 Name of Satellite
5.	1240/2734	Payload #1 Launch Weight, kg/lb
6.	652/1438	Payload #1 On-Orbit Weight, kg/lb
7.	68.2%	Ratio of Launch Weight/Max Weight
8.	0.284%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$21,214	Cost per Pound to Orbit (Not GTO)
10.	$40,334	Cost per Pound to Final Circular Orbit
11.	1426/3144	15% Handicap Launch Weight, kg/lb
12.	750/1653	15% Handicap On-Orbit Weight, kg/lb
13.	$18,448	15% Handicap GTO Cost per Pound
14.	$35,088	15% Handicap GEO Cost per Pound

Delta II 7925, Flight 9 of 16 (20,000km Final Orbit, Not GEO)

1.	211	Launch Reference Number
2.	7 Jul 92	Launch Date
3.	ETR-17B	Launch Facility
4.	Navstar 2-14	Payload #1 Name of Satellite
5.	1881/4148	Payload #1 Launch Weight, kg/lb
6.	930/2051	Payload #1 On-Orbit Weight, kg/lb
7.	Max Weight Unknown	Ratio of Launch Weight/Max Weight
8.	0.405%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$10,366	Cost per Pound to Orbit (Not GTO)
10.	$20,965	Cost per Pound to Final Circular Orbit
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

Delta II 7925, Flight 10 of 16

1.	213	Launch Reference Number
2.	31 Aug 92	Launch Date
3.	ETR-17B	Launch Facility
4.	Satcom C4	Payload #1 Name of Satellite
5.	1402/3091	Payload #1 Launch Weight, kg/lb
6.	791/1744	Payload #1 On-Orbit Weight, kg/lb
7.	77.1%	Ratio of Launch Weight/Max Weight
8.	0.344%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$18,764	Cost per Pound to Orbit (Not GTO)
10.	$33,257	Cost per Pound to Final Circular Orbit
11.	1612/3555	15% Handicap Launch Weight, kg/lb
12.	910/2006	15% Handicap On-Orbit Weight, kg/lb
13.	$16,315	15% Handicap GTO Cost per Pound
14.	$28,913	15% Handicap GEO Cost per Pound

Delta II 7925, Flight 11 of 16 (20,000km Final Orbit, Not GEO)

1.	214	Launch Reference Number
2.	9 Sep 92	Launch Date
3.	ETR-17A	Launch Facility
4.	Navstar 2-15	Payload #1 Name of Satellite
5.	1881/4148	Payload #1 Launch Weight, kg/lb
6.	930/2051	Payload #1 On-Orbit Weight, kg/lb
7.	Max Weight Unknown	Ratio of Launch Weight/Max Weight
8.	0.405%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$10,366	Cost per Pound to Orbit (Not GTO)
10.	$20,965	Cost per Pound to Final Circular Orbit
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

Delta II 7925, Flight 12 of 16

1.	215	Launch Reference Number
2.	12 Oct 92	Launch Date
3.	ETR-17B	Launch Facility
4.	DFS 3	Payload #1 Name of Satellite
5.	1411/3111	Payload #1 Launch Weight, kg/lb
6.	850/1874	Payload #1 On-Orbit Weight, kg/lb
7.	77.6%	Ratio of Launch Weight/Max Weight
8.	0.370%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$18,644	Cost per Pound to Orbit (Not GTO)
10.	$30,950	Cost per Pound to Final Circular Orbit
11.	1623/3578	15% Handicap Launch Weight, kg/lb
12.	978/2155	15% Handicap On-Orbit Weight, kg/lb
13.	$16,210	15% Handicap GTO Cost per Pound
14.	$26,914	15% Handicap GEO Cost per Pound

Delta II 7925, Flight 13 of 16 (20,000km Final Orbit, Not GEO)

1.	216	Launch Reference Number
2.	22 Nov 92	Launch Date
3.	ETR-17A	Launch Facility
4.	Navstar 2-16	Payload #1 Name of Satellite
5.	1881/4148	Payload #1 Launch Weight, kg/lb
6.	930/2051	Payload #1 On-Orbit Weight, kg/lb
7.	Max Weight Unknown	Ratio of Launch Weight/Max Weight
8.	0.405%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$10,366	Cost per Pound to Orbit (Not GTO)
10.	$20,965	Cost per Pound to Final Circular Orbit
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

Delta II 7925, Flight 14 of 16 (20,000km Final Orbit, Not GEO)

1.	217	Launch Reference Number
2.	18 Dec 92	Launch Date
3.	ETR-17B	Launch Facility
4.	Navstar 2-17	Payload #1 Name of Satellite
5.	1881/4148	Payload #1 Launch Weight, kg/lb
6.	930/2051	Payload #1 On-Orbit Weight, kg/lb
7.	Max Weight Unknown	Ratio of Launch Weight/Max Weight
8.	0.405%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$10,366	Cost per Pound to Orbit (Not GTO)
10.	$20,965	Cost per Pound to Final Circular Orbit
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

Delta II 7925, Flight 15 of 16 (20,000km Final Orbit, Not GEO)

1.	218	Launch Reference Number
2.	3 Feb 93	Launch Date
3.	ETR-17A	Launch Facility
4.	Navstar 2-18	Payload #1 Name of Satellite
5.	1881/4148	Payload #1 Launch Weight, kg/lb
6.	930/2051	Payload #1 On-Orbit Weight, kg/lb
7.	Max Weight Unknown	Ratio of Launch Weight/Max Weight
8.	0.405%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$10,366	Cost per Pound to Orbit (Not GTO)
10.	$20,965	Cost per Pound to Final Circular Orbit
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

Delta II 7925, Flight 16 of 16 (20,000km Final Orbit, Not GEO)

1.	219	Launch Reference Number
2.	30 Mar 93	Launch Date
3.	ETR-17B	Launch Facility
4.	Navstar 2-19	Payload #1 Name of Satellite
5.	1881/4148	Payload #1 Launch Weight, kg/lb
6.	930/2051	Payload #1 On-Orbit Weight, kg/lb
7.	Max Weight Unknown	Ratio of Launch Weight/Max Weight
8.	0.405%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$10,366	Cost per Pound to Orbit (Not GTO)
10.	$20,965	Cost per Pound to Final Circular Orbit
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

APPENDIX F
JAPANESE "H" SERIES GEO LAUNCH VEHICLE SUMMARIES
1986-1993

H2

1.	H2	Name of Vehicle
2.	NASDA	Manufacturing Company
3.	Japan	Country
4.	GTO	Orbit
5.	4000	Max Payload (kg)
6.	8820	Max Payload (lb)
7.	264,000	Takeoff Weight (kg)
8.	582,120	Takeoff Weight (lb)
9.	1.52%	Payload to Takeoff Wt Ratio
10.	1	Number Launched to Date
11.	0	Number of Failures
12.	100%	Success Rate
13.	$150M/$60M Goal	Cost/Flight in 1993 $US, Now/Future
14.	$17,007/$6,803	Cost per Pound Max Load, Now/Future
15.	$14,661/$5,864	16% Handicap Cost/lb Max Load, N/F
16.	2	Number of Stages
17.	50	Overall Length (m)
18.	4	Diameter (m)
19.	Liquid	First Stage Propellant (Liq or Solid)
20.	Liquid Hydrogen	First Stage Fuel
21.	Liquid Oxygen	First Stage Oxidizer
22.	86,200	First Stage Fuel Mass (kg)
23.	1180	First Stage Thrust (kN), Vacuum
24.	449	First Stage Specific Impulse, Vacuum
25.	346	First Stage Duration of Thrust (Sec)
26.	2 ea Solid	Booster Stage Propellant (Liq or Solid)
27.	HTPB	Booster Stage Fuel
28.	HTPB	Booster Stage Oxidizer
29.	59,150	Booster Stage Fuel Mass (kg)
30.	1,560	Booster Stage Thrust (Kn), Sea Level
31.	253	Booster Stage Specific Impulse, Vacuum
32.	94	Booster Stage Duration of Thrust (Sec)
33.	Liquid	Second Stage Propellant (Liq or Solid)
34.	Liquid Hydrogen	Second Stage Fuel
35.	Liquid Oxygen	Second Stage Oxidizer
36.	16,700	Second Stage Fuel Mass (kg)
37.	121.5	Second Stage Thrust (Kn), Vacuum
38.	451	Second Stage Specific Impulse, Vacuum
39.	609 or 403 + 197	Second Stage Duration of Thrust (Sec)
40.	N/A	Third Stage Propellant (Liq or Solid)
41.	N/A	Third Stage Fuel
42.	N/A	Third Stage Oxidizer
43.	N/A	Third Stage Fuel Mass (kg)
44.	N/A	Third Stage Thrust (Kn), Vacuum
45.	N/A	Third Stage Specific Impulse, Vacuum
46.	N/A	Third Stage Duration of Thrust (Sec)

H2, Flight 1 of 1

1.	1	Launch Reference Number
2.	4 Feb 94	Launch Date
3.	Tanegashima	Launch Facility
4.	Evaluation Payload	Payload #1 Name of Satellite
5.	2395/5,280	Payload #1 Launch Weight, kg/lb
6.	----	Payload #1 On-Orbit Weight, kg/lb
7.	59.9%	Ratio of Launch Weight/Max Weight
8.	----	Ratio of On-Orbit Wt/Takeoff Wt
9.	$28,409	Cost per Pound to GTO
10.	----	Cost per Pound to GEO
11.	2778/6125	16% Handicap Launch Weight, kg/lb
12.	----	16% Handicap On-Orbit Weight, kg/lb
13.	$24,490	16% Handicap GTO Cost per Pound
14.	----	16% Handicap GEO Cost per Pound

H1

1.	H1	Name of Vehicle
2.	NASDA	Manufacturing Company
3.	Japan	Country
4.	GTO	Orbit
5.	1100	Max Payload (kg)
6.	2426	Max Payload (lb)
7.	140,400	Takeoff Weight (kg)
8.	309,582	Takeoff Weight (lb)
9.	0.783%	Payload to Takeoff Wt Ratio
10.	9	Number Launched to Date
11.	0	Number of Failures
12.	100%	Success Rate
13.	$57M	Cost per Flight in 1993 $US
14.	$23,495	Cost per Pound Max Load
15.	$20,254	16% Handicap Cost/lb Max Load
16.	3	Number of Stages
17.	40.3	Overall Length (m)
18.	2.44	Diameter (m)
19.	Liquid	First Stage Propellant (Liq or Solid)
20.	RJ-1	First Stage Fuel
21.	Liquid Oxygen	First Stage Oxidizer
22.	93,420	First Stage Fuel Mass (kg)
23.	862.9	First Stage Thrust (kN), Vacuum
24.	289	First Stage Specific Impulse, Vacuum
25.	270/274 Verniers	First Stage Duration of Thrust (Sec)
26.	9 ea Solid	Booster Stage Propellant (Liq or Solid)
27.	Polybutadiene	Booster Stage Fuel
28.	Polybutadiene	Booster Stage Oxidizer
29.	3,730	Booster Stage Fuel Mass (kg)
30.	232	Booster Stage Thrust (Kn), Sea Level
31.	247	Booster Stage Specific Impulse, Vacuum
32.	39	Booster Stage Duration of Thrust (Sec)
33.	Liquid	Second Stage Propellant (Liq or Solid)
34.	Liquid Hydrogen	Second Stage Fuel
35.	Liquid Oxygen	Second Stage Oxidizer
36.	8,800	Second Stage Fuel Mass (kg)
37.	102.96	Second Stage Thrust (Kn), Vacuum
38.	441	Second Stage Specific Impulse, Vacuum
39.	370	Second Stage Duration of Thrust (Sec)
40.	Solid	Third Stage Propellant (Liq or Solid)
41.	Polybutadiene	Third Stage Fuel
42.	Polybutadiene	Third Stage Oxidizer
43.	1,800	Third Stage Fuel Mass (kg)
44.	77.45	Third Stage Thrust (Kn), Vacuum
45.	298	Third Stage Specific Impulse, Vacuum
46.	68	Third Stage Duration of Thrust (Sec)

H1, Flight 1 of 9 (LEO, Not GEO)

1.	15	Launch Reference Number
2.	13 Aug 86	Launch Date
3.	Tanegashima	Launch Facility
4.	EGP and Fuji 1	Payload #1 Name of Satellite
5.	730/1610	Payload #1 Launch Weight, kg/lb
6.	730/1610	Payload #1 On-Orbit Weight, kg/lb
7.	----	Ratio of Launch Weight/Max Weight
8.	----	Ratio of On-Orbit Wt/Takeoff Wt
9.	----	Cost per Pound to Orbit (Not GTO)
10.	----	Cost per Pound to Final Circular Orbit
11.	N/A	16% Handicap Launch Weight, kg/lb
12.	N/A	16% Handicap On-Orbit Weight, kg/lb
13.	N/A	16% Handicap GTO Cost per Pound
14.	N/A	16% Handicap GEO Cost per Pound

H1, Flight 2 of 9

1.	17	Launch Reference Number
2.	27 Aug 87	Launch Date
3.	Tanegashima	Launch Facility
4.	ETS-5	Payload #1 Name of Satellite
5.	1081/2384	Payload #1 Launch Weight, kg/lb
6.	550/1213	Payload #1 On-Orbit Weight, kg/lb
7.	98.3%	Ratio of Launch Weight/Max Weight
8.	0.392%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$23,909	Cost per Pound to GTO
10.	$46,991	Cost per Pound to GEO
11.	1254/2765	16% Handicap Launch Weight, kg/lb
12.	638/1407	16% Handicap On-Orbit Weight, kg/lb
13.	$20,615	16% Handicap GTO Cost per Pound
14.	$40,512	16% Handicap GEO Cost per Pound

H1, Flight 3 of 9

1.	18	Launch Reference Number
2.	19 Feb 88	Launch Date
3.	Tanegashima	Launch Facility
4.	CS-3A	Payload #1 Name of Satellite
5.	1099/2423	Payload #1 Launch Weight, kg/lb
6.	550/1213	Payload #1 On-Orbit Weight, kg/lb
7.	99.9%	Ratio of Launch Weight/Max Weight
8.	0.392%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$23,525	Cost per Pound to GTO
10.	$46,991	Cost per Pound to GEO
11.	1275/2811	16% Handicap Launch Weight, kg/lb
12.	638/1407	16% Handicap On-Orbit Weight, kg/lb
13.	$20,277	16% Handicap GTO Cost per Pound
14.	$40,512	16% Handicap GEO Cost per Pound

H1, Flight 4 of 9

1.	19	Launch Reference Number
2.	16 Sep 88	Launch Date
3.	Tanegashima	Launch Facility
4.	CS-3B	Payload #1 Name of Satellite
5.	1099/2423	Payload #1 Launch Weight, kg/lb
6.	550/1213	Payload #1 On-Orbit Weight, kg/lb
7.	99.9%	Ratio of Launch Weight/Max Weight
8.	0.392%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$23,525	Cost per Pound to GTO
10.	$46,991	Cost per Pound to GEO
11.	1275/2811	16% Handicap Launch Weight, kg/lb
12.	638/1407	16% Handicap On-Orbit Weight, kg/lb
13.	$20,277	16% Handicap GTO Cost per Pound
14.	$40,512	16% Handicap GEO Cost per Pound

H1, Flight 5 of 9

1.	20	Launch Reference Number
2.	5 Sep 89	Launch Date
3.	Tanegashima	Launch Facility
4.	GMS-4	Payload #1 Name of Satellite
5.	725/1599	Payload #1 Launch Weight, kg/lb
6.	325/717	Payload #1 On-Orbit Weight, kg/lb
7.	65.9%	Ratio of Launch Weight/Max Weight
8.	0.231%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$35,647	Cost per Pound to GTO
10.	$79,498	Cost per Pound to GEO
11.	841/1854	16% Handicap Launch Weight, kg/lb
12.	377/831	16% Handicap On-Orbit Weight, kg/lb
13.	$30,744	16% Handicap GTO Cost per Pound
14.	$68,592	16% Handicap GEO Cost per Pound

H1, Flight 6 of 9 (LEO, Not GEO)

1.	21	Launch Reference Number
2.	7 Feb 90	Launch Date
3.	Tanegashima	Launch Facility
4.	MOS-1B/Fuji-2/Debut	Payload #1 Name of Satellite
5.	----	Payload #1 Launch Weight, kg/lb
6.	----	Payload #1 On-Orbit Weight, kg/lb
7.	----	Ratio of Launch Weight/Max Weight
8.	----	Ratio of On-Orbit Wt/Takeoff Wt
9.	----	Cost per Pound to GTO
10.	----	Cost per Pound to GEO
11.	N/A	16% Handicap Launch Weight, kg/lb
12.	N/A	16% Handicap On-Orbit Weight, kg/lb
13.	N/A	16% Handicap GTO Cost per Pound
14.	N/A	16% Handicap GEO Cost per Pound

H1, Flight 7 of 9

1.	22	Launch Reference Number
2.	28 Aug 90	Launch Date
3.	Tanegashima	Launch Facility
4.	BS-3A	Payload #1 Name of Satellite
5.	1115/2459	Payload #1 Launch Weight, kg/lb
6.	550/1213	Payload #1 On-Orbit Weight, kg/lb
7.	101.4%	Ratio of Launch Weight/Max Weight
8.	0.392%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$23,180	Cost per Pound to GTO
10.	$46,991	Cost per Pound to GEO
11.	1293/2852	16% Handicap Launch Weight, kg/lb
12.	638/1407	16% Handicap On-Orbit Weight, kg/lb
13.	$19,986	16% Handicap GTO Cost per Pound
14.	$40,512	16% Handicap GEO Cost per Pound

H1, Flight 8 of 9

1.	23	Launch Reference Number
2.	25 Aug 91	Launch Date
3.	Tanegashima	Launch Facility
4.	BS-3B	Payload #1 Name of Satellite
5.	1115/2459	Payload #1 Launch Weight, kg/lb
6.	550/1213	Payload #1 On-Orbit Weight, kg/lb
7.	101.4%	Ratio of Launch Weight/Max Weight
8.	0.392%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$23,180	Cost per Pound to GTO
10.	$46,991	Cost per Pound to GEO
11.	1293/2852	16% Handicap Launch Weight, kg/lb
12.	638/1407	16% Handicap On-Orbit Weight, kg/lb
13.	$19,986	16% Handicap GTO Cost per Pound
14.	$40,512	16% Handicap GEO Cost per Pound

H1, Flight 9 of 9 (LEO, Not GEO)

1.	24	Launch Reference Number
2.	11 Feb 92	Launch Date
3.	Tanegashima	Launch Facility
4.	JERS-1	Payload #1 Name of Satellite
5.	----	Payload #1 Launch Weight, kg/lb
6.	----	Payload #1 On-Orbit Weight, kg/lb
7.	----	Ratio of Launch Weight/Max Weight
8.	----	Ratio of On-Orbit Wt/Takeoff Wt
9.	----	Cost per Pound to GTO
10.	----	Cost per Pound to GEO
11.	N/A	16% Handicap Launch Weight, kg/lb
12.	N/A	16% Handicap On-Orbit Weight, kg/lb
13.	N/A	16% Handicap GTO Cost per Pound
14.	N/A	16% Handicap GEO Cost per Pound

APPENDIX G
PROTON GEO LAUNCH VEHICLE SUMMARIES
1965-1993

PROTON K SL-12

1.	Proton	Name of Vehicle
2.	NPO Energia	Manufacturing Company
3.	CIS	Country
4.	GTO	Orbit
5.	4600	Max Payload (kg)
6.	10,143	Max Payload (lb)
7.	690,000	Takeoff Weight (kg)
8.	1,521,450	Takeoff Weight (lb)
9.	0.667%	Payload to Takeoff Wt Ratio
10.	179	Number Launched to Date
11.	12	Number of Failures
12.	86.6%	Success Rate
13.	$36M	Cost per Flight in 1993 $US (Inmarsat)
14.	$3,549	Cost per Pound Max Load
15.	$2,909	22% Handicap Cost/lb Max Load
16.	4	Number of Stages
17.	57.7	Overall Length (m)
18.	7.4	Diameter (m)
19.	Liquid	First Stage Propellant (Liq or Solid)
20.	UDMH	First Stage Fuel
21.	Nitrogen Tetroxide	First Stage Oxidizer
22.	420,000	First Stage Fuel Mass (kg)
23.	8,844/10470	First Stage Thrust (kN), Sea/Vac
24.	285/317	First Stage Specific Impulse, Sea/Vac
25.	130	First Stage Duration of Thrust (Sec)
26.	Liquid	Second Stage Propellant (Liq or Solid)
27.	UDMH	Second Stage Fuel
28.	Nitrogen Tetroxide	Second Stage Oxidizer
29.	150,000	Second Stage Fuel Mass (kg)
30.	2,376	Second Stage Thrust (Kn), Vacuum
31.	317	Second Stage Specific Impulse, Vacuum
32.	327	Second Stage Duration of Thrust (Sec)
33.	Liquid	Third Stage Propellant (Liq or Solid)
34.	UDMH	Third Stage Fuel
35.	Nitrogen Tetroxide	Third Stage Oxidizer
36.	47,000	Third Stage Fuel Mass (kg)
37.	625	Third Stage Thrust (Kn), Vacuum
38.	325	Third Stage Specific Impulse, Vacuum
39.	250	Third Stage Duration of Thrust (Sec)
40.	Liquid	Fourth Stage Propellant (Liq or Solid)
41.	Kerosene	Fourth Stage Fuel
42.	Liquid Oxygen	Fourth Stage Oxidizer
43.	17,300	Fourth Stage Fuel Mass (kg)
44.	85	Fourth Stage Thrust (Kn), Vacuum
45.	352	Fourth Stage Specific Impulse, Vacuum
46.	600	Fourth Stage Duration of Thrust (Sec)

Proton K SL-12

1.	1-179	Launch Reference Number
2.	1965-1993	Launch Date
3.	Tyuratam	Launch Facility
4.	GEO Satellites	Payload #1 Name of Satellite
5.	4600/10,143	Payload #1 Launch Weight, kg/lb
6.	2500/5513	Payload #1 On-Orbit Weight, kg/lb
7.	0.362%	Ratio of Launch Weight/Max Weight
8.	100%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$3,549	Cost per Pound to GTO
10.	$6,530	Cost per Pound to GEO
11.	5612/12,374	22% Handicap Launch Weight, kg/lb
12.	3050/6725	22% Handicap On-Orbit Weight, kg/lb
13.	$2,909	22% Handicap GTO Cost per Pound
14.	$5,353	22% Handicap GEO Cost per Pound

APPENDIX H
SHUTTLE PAYLOAD TO GEO SUMMARIES
1985-1993

Shuttle

1.	Shuttle	Name of Vehicle
2.	NASA	Manufacturing Company
3.	USA	Country
4.	LEO (Not GTO)	Orbit
5.	24,950	Max Payload (kg)
6.	55,015	Max Payload (lb)
7.	2,040,000	Takeoff Weight (kg)
8.	4,498,200	Takeoff Weight (lb)
9.	1.22%	Payload to Takeoff Wt Ratio, LEO
10.	63	Number Launched to Date
11.	1	Number of Failures
12.	98.2%	Success Rate
13.	$330M/140M, Bay	Cost/Flight in 1993 $US, Cost/Charge
14.	$2,548 (LEO)	Cost per Pound Max Load to LEO
15.	$2,213 (LEO)	Handicap Cost/lb Max Load to LEO
16.	1	Number of Stages
17.	56.14	Overall Length (m)
18.	----	Diameter (m)
19.	Liquid	First Stage Propellant (Liq or Solid)
20.	Liquid Hydrogen	First Stage Fuel
21.	Liquid Oxygen	First Stage Oxidizer
22.	170,000	First Stage Fuel Mass (kg)
23.	2090 x 3	First Stage Thrust (kN), Vacuum
24.	455	First Stage Specific Impulse, Vacuum
25.	520	First Stage Duration of Thrust (Sec)
26.	2 ea Solid	Booster Quantity and Type
27.	TP-H1148 HB Polymer	Booster Fuel
28.	TP-H1148 HB Polymer	Booster Oxidizer
29.	503,487	Booster Fuel Mass (kg)
30.	11,520	Booster Thrust (Kn), Vacuum
31.	268.6	Booster Specific Impulse, Vacuum
32.	123.6	Booster Duration of Thrust (Sec)
33.	----	Second Stage Propellant (Liq or Solid)
34.	----	Second Stage Fuel
35.	----	Second Stage Oxidizer
36.	----	Second Stage Fuel Mass (kg)
37.	----	Second Stage Thrust (Kn), Vacuum
38.	----	Second Stage Specific Impulse, Vacuum
39.	----	Second Stage Duration of Thrust (Sec)
40.	----	Third Stage Propellant (Liq or Solid)
41.	----	Third Stage Fuel
42.	----	Third Stage Oxidizer
43.	----	Third Stage Fuel Mass (kg)
44.	----	Third Stage Thrust (Kn), Vacuum
45.	----	Third Stage Specific Impulse, Vacuum
46.	----	Third Stage Duration of Thrust (Sec)

Shuttle, Flight STS-51J

1.	STS-51J	Launch Reference Number
2.	3 Oct 85	Launch Date
3.	KSC	Launch Facility
4.	DSCS III 2/3	Payload #1 and #2 Name of Satellite
5.	16,840/37,132	Payload #1/2 Sat + IUS Weight, kg/lb
6.	2080/4586	Payload #1 On-Orbit Weight, kg/lb
7.	----	Ratio of Launch Weight/Max Weight
8.	----	Ratio of On-Orbit Wt/Takeoff Wt
9.	$85M	Cost for IUS
10.	$90,493	Cost per Pound to GEO
11.	----	15% Handicap Launch Weight, kg/lb
12.	2392/5274	15% Handicap On-Orbit Weight, kg/lb
13.	----	15% Handicap GTO Cost per Pound
14.	$78,688	15% Handicap GEO Cost per Pound

Shuttle, Flight STS-44

1.	STS-44	Launch Reference Number
2.	24 Nov 91	Launch Date
3.	KSC	Launch Facility
4.	DSP 16	Payload #1 Name of Satellite
5.	17,120/37,750	Payload #1 Sat + IUS Weight, kg/lb
6.	2360/5204	Payload #1 On-Orbit Weight, kg/lb
7.	----	Ratio of Launch Weight/Max Weight
8.	----	Ratio of On-Orbit Wt/Takeoff Wt
9.	$85M	Cost for IUS
10.	$79,746	Cost per Pound to GEO
11.	----	15% Handicap Launch Weight, kg/lb
12.	2714/5984	15% Handicap On-Orbit Weight, kg/lb
13.	----	15% Handicap GTO Cost per Pound
14.	$69,352	15% Handicap GEO Cost per Pound

Shuttle, Flight STS-54

1.	STS-54	Launch Reference Number
2.	13 Jan 93	Launch Date
3.	KSC	Launch Facility
4.	TDRS 6	Payload #1 Name of Satellite
5.	16,960/37,397	Payload #1 Sat + IUS Weight, kg/lb
6.	2200/4851	Payload #1 On-Orbit Weight, kg/lb
7.	----	Ratio of Launch Weight/Max Weight
8.	----	Ratio of On-Orbit Wt/Takeoff Wt
9.	$85M	Cost for IUS
10.	$85,549	Cost per Pound to GEO
11.	----	15% Handicap Launch Weight, kg/lb
12.	2530/5579	15% Handicap On-Orbit Weight, kg/lb
13.	----	15% Handicap GTO Cost per Pound
14.	$74,386	15% Handicap GEO Cost per Pound

APPENDIX I
TAURUS/PAGASUS GEO LAUNCH VEHICLE FAMILY SUMMARIES
1990-1993

Taurus 120/120XL/120XLS

1.	Taurus	Name of Vehicle
2.	Orbital Sciences	Manufacturing Company
3.	USA	Country
4.	GTO	Orbit
5.	514/595/736	Max Payload (kg), 120/120XL/120XLS
6.	1133/1312/1623	Max Payload (lb), 120/120XL/120XLS
7.	72576/76627/102589	Takeoff Weight (kg), 120/120XL/120XLS
8.	160,030/168,962	Takeoff Weight (lb), 120/120XL
	226,209	Takeoff Weight (lb), 120XLS
9.	0.708/0.776/0.717%	Payload to Takeoff Wt Ratio, 120/XL/XLS
10.	1 (Not GTO)	Number Launched to Date
11.	0	Number of Failures
12.	100%	Success Rate
13.	$18M	Cost per Flight in 1993 $US
14.	$15887/13720/11091	Cost/Pound Max Load to GTO, 120/XL/XLS
15.	$13815/11930/9644	Handicap Cost/lb Max Load to GTO
16.	4	Number of Stages
17.	27.56	Overall Length (m)
18.	2.36	Diameter (m)
19.	Solid Castor 120	Zero Stage Propellant (Liq or Solid)
20.	HTPB	Zero Stage Fuel
21.	HTPB	Zero Stage Oxidizer
22.	48,988	Zero Stage Fuel Mass (kg)
23.	1942	Zero Stage Thrust (kN), Vacuum
24.	279.7	Zero Stage Specific Impulse, Vacuum
25.	56	Zero Stage Duration of Thrust (Sec)
26.	2 ea Solid GEM	Booster Quantity and Type
27.	HTPB	Booster Fuel
28.	HTPB	Booster Oxidizer
29.	11,703	Booster Fuel Mass (kg)
30.	439.77/492.93	Booster Thrust (Kn), Sea Level/Vacuum
31.	273	Booster Specific Impulse, Vacuum
32.	63.7	Booster Duration of Thrust (Sec)
33.	Solid Orion 50S	First Stage Propellant (Liq or Solid)
34.	HTPB	First Stage Fuel
35.	HTPB	First Stage Oxidizer
36.	12,152/15,051	First Stage Fuel Mass (kg), 120/120XL
37.	486.7	First Stage Thrust (Kn), Vacuum
38.	238	First Stage Specific Impulse, Vacuum
39.	64.3/72.3	First Stage Thrust Duration (Sec)
40.	Solid Orion 50	Second Stage Propellant (Liq or Solid)
41.	HTPB	Second Stage Fuel
42.	HTPB	Second Stage Oxidizer
43.	3025/3914	Second Stage Fuel Mass (kg), 120/120XL
44.	122.8	Second Stage Thrust (Kn), Vacuum

45.	226	Second Stage Specific Impulse, Vacuum
46.	70.7	Second Stage Duration of Thrust (Sec)
47.	Solid Star 37XFP	Third Stage Propellant (Liq or Solid)
48.	HTPB	Third Stage Fuel
49.	HTPB	Third Stage Oxidizer
50.	884.4	Third Stage Fuel Mass (kg)
51.	32.9	Third Stage Thrust (Kn), Vacuum
52.	289.9	Third Stage Specific Impulse, Vacuum
53.	66.5	Third Stage Duration of Thrust (Sec)

Pagasus XL

1.	Pegasus	Name of Vehicle
2.	Orbital Sciences	Manufacturing Company
3.	USA	Country
4.	GTO	Orbit
5.	165	Max Payload (kg)
6.	364	Max Payload (lb)
7.	22,583	Launch Weight (kg)
8.	49,796	Launch Weight (lb)
9.	0.731%	Payload to Takeoff Wt Ratio, 120/XL/XLS
10.	4 (Not GTO)	Number Launched to Date
11.	0	Number of Failures
12.	100%	Success Rate
13.	$12M	Cost per Flight in 1993 $US
14.	$32,967	Cost per Pound Max Load to GTO
15.	$28,667	Handicap Cost/lb Max Load to GTO
16.	3	Number of Stages
17.	27.56	Overall Length (m)
18.	2.36	Diameter (m)
19.	Lockheed L-1011	Zero Stage (Airplane Drop)
20.	Solid Orion 50S	First Stage Propellant (Liq or Solid)
21.	HTPB	First Stage Fuel
22.	HTPB	First Stage Oxidizer
23.	15,051	First Stage Fuel Mass (kg)
24.	486.7	First Stage Thrust (Kn), Vacuum
25.	238	First Stage Specific Impulse, Vacuum
26.	72.3	First Stage Duration of Thrust (Sec)
27.	Solid Orion 50	Second Stage Propellant (Liq or Solid)
28.	HTPB	Second Stage Fuel
29.	HTPB	Second Stage Oxidizer
30.	3914	Second Stage Fuel Mass (kg)
31.	122.8	Second Stage Thrust (Kn), Vacuum
32.	226	Second Stage Specific Impulse, Vacuum
33.	70.7	Second Stage Duration of Thrust (Sec)
34.	Solid Orion 38	Third Stage Propellant (Liq or Solid)
35.	HTPB	Third Stage Fuel
36.	HTPB	Third Stage Oxidizer
37.	775	Third Stage Fuel Mass (kg)
38.	34.57	Third Stage Thrust (Kn), Vacuum
39.	300	Third Stage Specific Impulse, Vacuum
40.	66	Third Stage Duration of Thrust (Sec)

APPENDIX J
TITAN GEO LAUNCH VEHICLE FAMILY SUMMARIES
1988-1993

Titan 4 (Centaur + SRMU)

1.	Titan 4	Name of Vehicle
2.	Martin Marietta	Manufacturing Company
3.	USA	Country
4.	GEO/GTO	Orbit
5.	5773/10496	Max Payload (kg), GEO/GTO (Equivalent)
6.	12729/23144	Max Payload (lb), GEO/GTO (Equivalent)
7.	939,301	Takeoff Weight (kg)
8.	2,071,158	Takeoff Weight (lb)
9.	0.615/1.12%	Payload to Takeoff Wt Ratio, GEO/GTO
10.	0	Number Launched to Date
11.	0	Number of Failures
12.	N/A	Success Rate
13.	$230M	Cost per Flight in 1993 $US, Mil
14.	$18,069/$9,938	Cost per Pound Max Load to GEO/GTO
15.	$15,712/$8,642	Handicap Cost/lb Max Load to GEO/GTO
16.	3	Number of Stages
17.	63.14	Overall Length (m)
18.	3.05	Diameter (m)
19.	Liquid	First Stage Propellant (Liq or Solid)
20.	Aerozine-50	First Stage Fuel
21.	Nitrogen Tetroxide	First Stage Oxidizer
22.	170,000	First Stage Fuel Mass (kg)
23.	2,437.8	First Stage Thrust (kN), Vacuum
24.	301	First Stage Specific Impulse, Vacuum
25.	186	First Stage Duration of Thrust (Sec)
26.	2 ea Solid	Booster Quantity and Type
27.	HTPB	Booster Fuel
28.	HTPB	Booster Oxidizer
29.	344,400	Booster Fuel Mass (kg)
30.	7,562	Booster Thrust (Kn), Sea Level
31.	324	Booster Specific Impulse, Vacuum
32.	145	Booster Duration of Thrust (Sec)
33.	Liquid	Second Stage Propellant (Liq or Solid)
34.	Aerozine-50	Second Stage Fuel
35.	Nitrogen Tetroxide	Second Stage Oxidizer
36.	38,400	Second Stage Fuel Mass (kg)
37.	472.0	Second Stage Thrust (Kn), Vacuum
38.	301	Second Stage Specific Impulse, Vacuum
39.	240	Second Stage Duration of Thrust (Sec)
40.	Centaur Liquid	Third Stage Propellant (Liq or Solid)
41.	Liquid Hydrogen	Third Stage Fuel
42.	Liquid Oxygen	Third Stage Oxidizer
43.	23,000	Third Stage Fuel Mass (kg)
44.	146.8	Third Stage Thrust (Kn), Vacuum
45.	402	Third Stage Specific Impulse, Vacuum
46.	617 Total	Third Stage Duration of Thrust (Sec)

Titan 4 (Centaur + SRM)

1.	Titan 4	Name of Vehicle
2.	Martin Marietta	Manufacturing Company
3.	USA	Country
4.	GEO/GTO	Orbit
5.	4545/8264	Max Payload (kg), GEO/GTO (Equivalent)
6.	10022/18222	Max Payload (lb), GEO/GTO (Equivalent)
7.	868,644	Takeoff Weight (kg)
8.	1,915360	Takeoff Weight (lb)
9.	0.523/0.951%	Payload to Takeoff Wt Ratio, GEO/GTO
10.	1	Number Launched to Date
11.	0	Number of Failures
12.	100%	Success Rate
13.	$220M	Cost per Flight in 1993 $US, Mil
14.	$21,952/$12,073	Cost per Pound Max Load to GEO/GTO
15.	$19,088/$10,499	Handicap Cost/lb Max Load to GEO/GTO
16.	3	Number of Stages
17.	63.14	Overall Length (m)
18.	3.05	Diameter (m)
19.	Liquid	First Stage Propellant (Liq or Solid)
20.	Aerozine-50	First Stage Fuel
21.	Nitrogen Tetroxide	First Stage Oxidizer
22.	170,000	First Stage Fuel Mass (kg)
23.	2,437.8	First Stage Thrust (kN), Vacuum
24.	301	First Stage Specific Impulse, Vacuum
25.	186	First Stage Duration of Thrust (Sec)
26.	2 ea Solid	Booster Quantity and Type
27.	PBAN	Booster Fuel
28.	PBAN	Booster Oxidizer
29.	295,500	Booster Fuel Mass (kg)
30.	7,117	Booster Thrust (Kn), Sea Level
31.	272	Booster Specific Impulse, Vacuum
32.	126.5	Booster Duration of Thrust (Sec)
33.	Liquid	Second Stage Propellant (Liq or Solid)
34.	Aerozine-50	Second Stage Fuel
35.	Nitrogen Tetroxide	Second Stage Oxidizer
36.	38,400	Second Stage Fuel Mass (kg)
37.	472.0	Second Stage Thrust (Kn), Vacuum
38.	301	Second Stage Specific Impulse, Vacuum
39.	240	Second Stage Duration of Thrust (Sec)
40.	Centaur Liquid	Third Stage Propellant (Liq or Solid)
41.	Liquid Hydrogen	Third Stage Fuel
42.	Liquid Oxygen	Third Stage Oxidizer
43.	23,000	Third Stage Fuel Mass (kg)
44.	146.8	Third Stage Thrust (Kn), Vacuum
45.	402	Third Stage Specific Impulse, Vacuum
46.	617 Total	Third Stage Duration of Thrust (Sec)

Titan 4 (IUS + SRMU)

1.	Titan 4	Name of Vehicle
2.	Martin Marietta	Manufacturing Company
3.	USA	Country
4.	GEO/GTO	Orbit
5.	2860/5200	Max Payload (kg), GEO/GTO (Equivalent)
6.	6306/11465	Max Payload (lb), GEO/GTO (Equivalent)
7.	924,515	Takeoff Weight (kg)
8.	2,038,556	Takeoff Weight (lb)
9.	0.309/0.562%	Payload to Takeoff Wt Ratio, GEO/GTO
10.	0	Number Launched to Date
11.	0	Number of Failures
12.	N/A	Success Rate
13.	$200M	Cost per Flight in 1993 $US, Mil
14.	$31,716/$17,444	Cost per Pound Max Load to GEO/GTO
15.	$27,579/$15,169	Handicap Cost/lb Max Load to GEO/GTO
16.	3	Number of Stages
17.	63.14	Overall Length (m)
18.	3.05	Diameter (m)
19.	Liquid	First Stage Propellant (Liq or Solid)
20.	Aerozine-50	First Stage Fuel
21.	Nitrogen Tetroxide	First Stage Oxidizer
22.	170,000	First Stage Fuel Mass (kg)
23.	2,437.8	First Stage Thrust (kN), Vacuum
24.	301	First Stage Specific Impulse, Vacuum
25.	186	First Stage Duration of Thrust (Sec)
26.	2 ea Solid	Booster Quantity and Type
27.	HTPB	Booster Fuel
28.	HTPB	Booster Oxidizer
29.	344,400	Booster Fuel Mass (kg)
30.	7,562	Booster Thrust (Kn), Sea Level
31.	324	Booster Specific Impulse, Vacuum
32.	145	Booster Duration of Thrust (Sec)
33.	Liquid	Second Stage Propellant (Liq or Solid)
34.	Aerozine-50	Second Stage Fuel
35.	Nitrogen Tetroxide	Second Stage Oxidizer
36.	38,400	Second Stage Fuel Mass (kg)
37.	472.0	Second Stage Thrust (Kn), Vacuum
38.	301	Second Stage Specific Impulse, Vacuum
39.	240	Second Stage Duration of Thrust (Sec)
40.	IUS Solid	Third Stage Propellant (Liq or Solid)
41.	HTPB	Third Stage Propellent, Stage 1
42.	HTPB	Third Stage Propellent, Stage 2
43.	9,818 + 2,722	Third Stage Fuel Mass (kg), Stage 1/2
44.	202.8/82.3	Third Stage Thrust (Kn), Vac, Stage 1/2
45.	295.5/303.5	Third Stage Specific Impulse, Vacuum
46.	152/289	Third Stage Thrust Duration (Sec), 1/2

Titan 4 (IUS + SRM)

1.	Titan 4	Name of Vehicle
2.	Martin Marietta	Manufacturing Company
3.	USA	Country
4.	GEO/GTO	Orbit
5.	2364/4298	Max Payload (kg), GEO/GTO (Equivalent)
6.	5213/9478	Max Payload (lb), GEO/GTO (Equivalent)
7.	910,018	Takeoff Weight (kg)
8.	2,006,590	Takeoff Weight (lb)
9.	0.260/0.472%	Payload to Takeoff Wt Ratio, GEO/GTO
10.	2	Number Launched to Date
11.	0	Number of Failures
12.	100%	Success Rate
13.	$190M	Cost per Flight in 1993 $US, Mil
14.	$36,447/$20,046	Cost per Pound Max Load to GEO/GTO
15.	$31,693/$17,431	Handicap Cost/lb Max Load to GEO/GTO
16.	3	Number of Stages
17.	63.14	Overall Length (m)
18.	3.05	Diameter (m)
19.	Liquid	First Stage Propellant (Liq or Solid)
20.	Aerozine-50	First Stage Fuel
21.	Nitrogen Tetroxide	First Stage Oxidizer
22.	170,000	First Stage Fuel Mass (kg)
23.	2,437.8	First Stage Thrust (kN), Vacuum
24.	301	First Stage Specific Impulse, Vacuum
25.	186	First Stage Duration of Thrust (Sec)
26.	2 ea Solid	Booster Quantity and Type
27.	PBAN	Booster Fuel
28.	PBAN	Booster Oxidizer
29.	295,500	Booster Fuel Mass (kg)
30.	7,117	Booster Thrust (Kn), Sea Level
31.	272	Booster Specific Impulse, Vacuum
32.	126.5	Booster Duration of Thrust (Sec)
33.	Liquid	Second Stage Propellant (Liq or Solid)
34.	Aerozine-50	Second Stage Fuel
35.	Nitrogen Tetroxide	Second Stage Oxidizer
36.	38,400	Second Stage Fuel Mass (kg)
37.	472.0	Second Stage Thrust (Kn), Vacuum
38.	301	Second Stage Specific Impulse, Vacuum
39.	240	Second Stage Duration of Thrust (Sec)
40.	IUS Solid	Third Stage Propellant (Liq or Solid)
41.	HTPB	Third Stage Propellent, Stage 1
42.	HTPB	Third Stage Propellent, Stage 2
43.	9,818 + 2,722	Third Stage Fuel Mass (kg), Stage 1/2
44.	202.8/82.3	Third Stage Thrust (Kn), Vac, Stage 1/2
45.	295.5/303.5	Third Stage Specific Impulse, Vacuum
46.	152/289	Third Stage Thrust Duration (Sec), 1/2

Titan 4 (IUS + SRM), Flight 1 of 6

1.	1	Launch Reference Number
2.	14 Jun 89	Launch Date
3.	ETR-41	Launch Facility
4.	DSP 14	Payload #1 Name of Satellite
5.	2360/5204	Payload #1 Launch Weight, kg/lb
6.	2360/5204	Payload #1 On-Orbit Weight, kg/lb
7.	99.8%	Ratio of Launch Weight/Max Weight
8.	0.259%	Ratio of On-Orbit Wt/Takeoff Wt
9.	----	Cost per Pound to GTO
10.	$36,510	Cost per Pound to GEO
11.	2714/5984	15% Handicap Launch Weight, kg/lb
12.	2714/5984	15% Handicap On-Orbit Weight, kg/lb
13.	----	15% Handicap GTO Cost per Pound
14.	$31,751	15% Handicap GEO Cost per Pound

Titan 4 (SRM), Flight 2 of 6 (LEO)

1.	2	Launch Reference Number
2.	8 Jun 90	Launch Date
3.	ETR-41	Launch Facility
4.	Military	Payload #1 Name of Satellite
5.	----	Payload #1 Launch Weight, kg/lb
6.	----	Payload #1 On-Orbit Weight, kg/lb
7.	----	Ratio of Launch Weight/Max Weight
8.	----	Ratio of On-Orbit Wt/Takeoff Wt
9.	N/A	Cost per Pound to GTO
10.	N/A	Cost per Pound to GEO
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

Titan 4 (IUS + SRM), Flight 3 of 6

1.	3	Launch Reference Number
2.	13 Nov 90	Launch Date
3.	ETR-41	Launch Facility
4.	DSP 15	Payload #1 Name of Satellite
5.	2360/5204	Payload #1 Launch Weight, kg/lb
6.	2360/5204	Payload #1 On-Orbit Weight, kg/lb
7.	99.8%	Ratio of Launch Weight/Max Weight
8.	0.259%	Ratio of On-Orbit Wt/Takeoff Wt
9.	----	Cost per Pound to GTO
10.	$36,510	Cost per Pound to GEO
11.	2714/5984	15% Handicap Launch Weight, kg/lb
12.	2714/5984	15% Handicap On-Orbit Weight, kg/lb
13.	----	15% Handicap GTO Cost per Pound
14.	$31,751	15% Handicap GEO Cost per Pound

Titan 4 (SRM), Flight 4 of 6 (LEO)

1.	4	Launch Reference Number
2.	8 Mar 91	Launch Date
3.	SLC-4E	Launch Facility
4.	Military	Payload #1 Name of Satellite
5.	----	Payload #1 Launch Weight, kg/lb
6.	----	Payload #1 On-Orbit Weight, kg/lb
7.	----	Ratio of Launch Weight/Max Weight
8.	----	Ratio of On-Orbit Wt/Takeoff Wt
9.	N/A	Cost per Pound to GTO
10.	N/A	Cost per Pound to GEO
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

Titan 4 (SRM), Flight 5 of 6 (LEO)

1.	5	Launch Reference Number
2.	8 Nov 91	Launch Date
3.	SLC-4E	Launch Facility
4.	Military	Payload #1 Name of Satellite
5.	----	Payload #1 Launch Weight, kg/lb
6.	----	Payload #1 On-Orbit Weight, kg/lb
7.	----	Ratio of Launch Weight/Max Weight
8.	----	Ratio of On-Orbit Wt/Takeoff Wt
9.	N/A	Cost per Pound to GTO
10.	N/A	Cost per Pound to GEO
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

Titan 4 (SRM), Flight 6 of 6 (LEO)

1.	6	Launch Reference Number
2.	28 Nov 92	Launch Date
3.	SLC-4E	Launch Facility
4.	Military	Payload #1 Name of Satellite
5.	----	Payload #1 Launch Weight, kg/lb
6.	----	Payload #1 On-Orbit Weight, kg/lb
7.	----	Ratio of Launch Weight/Max Weight
8.	----	Ratio of On-Orbit Wt/Takeoff Wt
9.	N/A	Cost per Pound to GTO
10.	N/A	Cost per Pound to GEO
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

Titan 3 (Commercial)

1.	Titan 3	Name of Vehicle
2.	Martin Marietta	Manufacturing Company
3.	USA	Country
4.	GTO	Orbit
5.	4000/4944	Max Payload (kg), Dual/Single
6.	8820/10902	Max Payload (lb), Dual/Single
7.	680,000	Takeoff Weight (kg)
8.	1,499,400	Takeoff Weight (lb)
9.	0.588/0.727%	Payload to Takeoff Wt Ratio, D/S
10.	4	Number Launched to Date
11.	1	Number of Failures
12.	75%	Success Rate
13.	$122/$110M	Cost per Flight in 1993 $US, D/S
14.	$13,832/$10,090	Cost per Pound Max Load to GTO, D/S
15.	$12,028/$8,774	Handicap Cost/lb Max Load to GTO
16.	2	Number of Stages
17.	47.3/44.06	Overall Length (m), Dual/Single
18.	3.05	Diameter (m)
19.	Liquid	First Stage Propellant (Liq or Solid)
20.	Aerozine-50	First Stage Fuel
21.	Nitrogen Tetroxide	First Stage Oxidizer
22.	109,700	First Stage Fuel Mass (kg)
23.	2,437.5	First Stage Thrust (kN), Vacuum
24.	301	First Stage Specific Impulse, Vacuum
25.	160	First Stage Duration of Thrust (Sec)
26.	2 ea Solid	Booster Quantity and Type
27.	UTP	Booster Fuel
28.	UTP	Booster Oxidizer
29.	210,630	Booster Fuel Mass (kg)
30.	6,227	Booster Thrust (Kn), Vacuum
31.	265	Booster Specific Impulse, Vac.
32.	113.7	Booster Duration of Thrust (Sec)
33.	Liquid	Second Stage Propellant (Liq or Solid)
34.	Aerozine-50	Second Stage Fuel
35.	Nitrogen Tetroxide	Second Stage Oxidizer
36.	28,600	Second Stage Fuel Mass (kg)
37.	467.04	Second Stage Thrust (Kn), Vacuum
38.	301	Second Stage Specific Impulse, Vacuum
39.	225	Second Stage Duration of Thrust (Sec)
40.	----	Third Stage Propellant (Liq or Solid)
41.	----	Third Stage Fuel
42.	----	Third Stage Oxidizer
43.	----	Third Stage Fuel Mass (kg)
44.	----	Third Stage Thrust (Kn), Vacuum
45.	----	Third Stage Specific Impulse, Vacuum
46.	----	Third Stage Duration of Thrust (Sec)

Titan 3 (Dual Satellites), Flight 1 of 4

1.	153	Launch Reference Number
2.	1 Jan 90	Launch Date
3.	ETR-40	Launch Facility
4.	Skynet 4A/JCSat 2	Payload #1 Name of Satellite
5.	3713/8187	Payload #1 Launch Weight, kg/lb
6.	2166/4776	Payload #1 On-Orbit Weight, kg/lb
7.	92.8%	Ratio of Launch Weight/Max Weight
8.	0.319%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$14,902	Cost per Pound to GTO
10.	$25,544	Cost per Pound to GEO
11.	4270/9415	15% Handicap Launch Weight, kg/lb
12.	2491/5492	15% Handicap On-Orbit Weight, kg/lb
13.	$12,958	15% Handicap GTO Cost per Pound
14.	$22,214	15% Handicap GEO Cost per Pound

Titan 3 (Single Satellite), Flight 2 of 4 (Failed)
(Intelsat 603 was rescued and reboosted by Shuttle)

1.	154	Launch Reference Number
2.	14 Mar 90	Launch Date
3.	ETR-40	Launch Facility
4.	Intelsat 603	Payload #1 Name of Satellite
5.	4600/10,143	Payload #1 Launch Weight, kg/lb
6.	2546/5614	Payload #1 On-Orbit Weight, kg/lb
7.	93.0%	Ratio of Launch Weight/Max Weight
8.	0.374%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$10,845	Cost per Pound to GTO
10.	$19,594	Cost per Pound to GEO
11.	5290/11,664	15% Handicap Launch Weight, kg/lb
12.	2928/6456	15% Handicap On-Orbit Weight, kg/lb
13.	$9,431	15% Handicap GTO Cost per Pound
14.	$17,038	15% Handicap GEO Cost per Pound

Titan 3 (Single Satellite), Flight 3 of 4

1.	155	Launch Reference Number
2.	23 Jun 90	Launch Date
3.	ETR-40	Launch Facility
4.	Intelsat 604	Payload #1 Name of Satellite
5.	4600/10,143	Payload #1 Launch Weight, kg/lb
6.	2546/5614	Payload #1 On-Orbit Weight, kg/lb
7.	93.0%	Ratio of Launch Weight/Max Weight
8.	0.374%	Ratio of On-Orbit Wt/Takeoff Wt
9.	$10,845	Cost per Pound to GTO
10.	$19,594	Cost per Pound to GEO
11.	5290/11,664	15% Handicap Launch Weight, kg/lb
12.	2928/6456	15% Handicap On-Orbit Weight, kg/lb
13.	$9,431	15% Handicap GTO Cost per Pound
14.	$17,038	15% Handicap GEO Cost per Pound

Titan 3 (Single Satellite), Flight 4 of 4 (Not GEO)

1.	156	Launch Reference Number
2.	25 Sep 92	Launch Date
3.	ETR-40	Launch Facility
4.	Mars Observer/TOS	Payload #1 Name of Satellite
5.	2565/5656	Payload #1 Launch Weight, kg/lb
6.	----	Payload #1 On-Orbit Weight, kg/lb
7.	----	Ratio of Launch Weight/Max Weight
8.	----	Ratio of On-Orbit Wt/Takeoff Wt
9.	----	Cost per Pound to GTO
10.	----	Cost per Pound to GEO
11.	N/A	15% Handicap Launch Weight, kg/lb
12.	N/A	15% Handicap On-Orbit Weight, kg/lb
13.	N/A	15% Handicap GTO Cost per Pound
14.	N/A	15% Handicap GEO Cost per Pound

EXECUTIVE SUMMARY

The U.S. commercial space launch program no longer dominates the world and is now playing "catch-up" with the world's first commercial launch company, Arianespace. The effort to regain the lead in commercial space launch market has been hindered by declining Department of Defense budgets. President Clinton's space policy prohibits expensive new launch vehicles and limits the Department of Defense to low-cost upgrades of existing launch vehicles. The U.S. government created the space sector and has an obligation to ensure a smooth and effective split from the emerging commercial space program. Until the ties are severed, the Department of Defense must consider commercial space launch interests when making decisions.

Ariane has provided an excellent "bench mark" for the U.S. to base future launch vehicle upgrades. The 198 commercial satellite launches since 1965 have provided a significant amount of data that were used to critically compare space launch vehicles. The dilemma was that U.S. space launch vehicles were found to be economically superior to Ariane for specific military payloads, but were not effective at launching commercial satellites over a wide range of payload weights. Ariane advantages were identified and low-cost recommendations have been made. If the U.S. sets the target of first equaling and then surpassing Ariane, the U.S. could once again dominate the world commercial launch market.

Arianespace recognized the potential of commercial space transportation and built a line of launch vehicles tailored specifically to the needs of the world's commercial satellite owners.[1] The Ariane family of space launch vehicles was designed to deliver payloads directly to geostationary transfer orbit because commercial payloads were typically geostationary communications and observation

satellites. They offer sixteen different launch configurations that cover a broad range of payload sizes, at consistently low prices. Ariane also offered multiple launch capability, allowing different sizes of satellites to be matched to one of the sixteen launch configurations. By so doing, they achieve a consistently high maximum payload. The Kourou (French Guiana) launch facility, located near the equator, provides a 15% energy savings over U.S. launched spacecraft bound for geostationary orbit.[2] The large family of Ariane space launch vehicles offers a number of significant advantages that explain why Arianespace captured the commercial launch market.

Nevertheless, the data shows that when Ariane launch vehicles are compared to equal size U.S. launch vehicles, the U.S. launch vehicles can be more economical in most cases. However, U.S. launch vehicles lack multiple launch capability and are capable of offering the lowest rates for only one size of satellite (the one that fits their maximum vehicle weight capacity). U.S. launch vehicles have offered considerably lower rates, typically 20%, for single payloads that utilized the maximum weight limits. Unfortunately, commercial payloads seldom matched the maximum weight limits of U.S. launch vehicles. The inevitable result was that most U.S. commercial launch vehicles flew with satellites that did not come close to filling up the payload area.

China, Japan, and Russia also have launch vehicles capable of providing competition with the United States. Currently they are being held at bay, because of U.S. satellite export restrictions which are enforceable only because U.S. companies still build most of the world's commercial satellites. The bad news is that foreign competition is growing.

After "bench marking" Ariane, by studying their performance strengths, a number of recommendations emerged that could be used by the U.S. to "catch-up" and "get ahead." Several of these recommendations involve funding outlays by the Department of Defense but the primary beneficiary appears to be the commercial space sector. While this may be true in part, the recommendations fit neatly within the Clinton Administration preferred "dual purpose" strategy whereby government spending benefits both the public and private sector. The recommended investments are relatively low cost but promise a high pay off.

Based on the study effort, the following recommendations were made:

Recommendation 1. The Department of Defense should fund a multiple payload option upgrade for the existing Atlas 1, 2, 2A, 2A Block 1, 2AS, and 2AS Block 1 configurations in order to compete with Ariane 4 multiple launch capability. They should also fund a multiple payload option (four or more satellites) upgrade the existing Titan 4, SRMU and Centaur configuration, in order to compete with the Ariane 5 multiple launch capability.

The most important difference between Ariane and U.S. launch vehicles is Ariane's ability to launch multiple payloads. This one advantage is the key to understanding why Ariane now dominates the commercial launch market. U.S. launch vehicles have full load rates as low as $7,500 per pound for the Atlas 2A, $9,300 for the Delta II 7925, and $8,800 for Titan 3, but their average costs for commercial satellites have been an incredibly high $17,500 per pound. Most of their launch vehicles flew with half empty cargo holds, because they were not able to match payloads to optimize the payload capacities.

The military Titan 3 has the same payload capacity as the Ariane 4 and has been launching dual payloads for the military for over twenty years. Titan 3 upgrades did not keep up with increasing commercial payload sizes and therefore were not competitive. The Titan 3 was also designed to be both a low-Earth and a GTO launch vehicle with design efficiency emphasis on low-Earth orbit injection. Because of the low-Earth design emphasis, the second stage must go to low-Earth orbit before sending the last stage on to a geostationary transfer orbit. This arrangement makes the Titan 3 less efficient at sending payloads to geostationary orbit. The Atlas, on the other hand, is a perfect candidate for a multiple payload configuration upgrade. The Atlas is smaller than the Ariane 4, but could lure many smaller payloads from Ariane. Ariane would then have a difficult time matching the larger payloads for multiple payload Ariane 4 and 5 configurations. Going after the smaller payloads is one way to regain part of the commercial launch market.

The Ariane 5, multiple launch configuration, will be capable of launching three satellites, which will provide a tremendous opportunity for Arianespace to match an even wider range of payloads to fill the spacecraft to its takeoff limit. Costs will be unbeatable unless the U.S. tops that with a Titan 4, SRMU and Centaur configuration, capable of launching four or more satellites to a geostationary transfer orbit. The Titan 4 also needs to be modified for a more efficient flight trajectory that would go directly to a geostationary transfer orbit instead of stopping at low-Earth orbit.

Recommendation 2. Fund economical launch vehicle upgrades which increase the number of launch configurations available, thus widening the payload window while keeping cost per pound rates low.

The second most significant technical advantage Ariane has is their ability to accommodate a wide variation of payload weights by using 16 different launch configurations. U.S. launch companies are forced to phase out older configurations when they are no longer needed for military payloads. Every effort should be made to increase the number of usable launch configurations for Atlas, Delta, and Titan launch vehicles.

Recommendation 3. The Department of Defense and commercial launch companies should build a launch facility near the equator to obtain a 15% savings in geostationary launch costs.

The third most significant advantage achieved by Ariane is their ability to launch from near the equator, which provides them with an immediate energy savings over comparable U.S. launch vehicles launched from Florida. A new U.S. launch facility would provide an immediate 15% cost savings for all flights to geostationary orbit. Ariane is not the only organization that will be taking advantage of the equatorial launches, representatives from the Space Transportation Systems, Ltd., of Australia, and four Russian enterprises have signed an exclusive 20 year, $750 million contract, for commercial equatorial launch services from Papua, New Guinea. The Russians claim the Proton can lift an additional 40% payload from the equator over their own northern Baikonur Cosmodrome launch facility.[3] The U.S. already owns two islands near the equator that could be used for a new U.S. launch facility. Baker and Howland Island, south of the Hawaiian Islands, are located closer to the equator than either New Guinea or Kourou. The initial investment would take many years to recover but the advantages may make the difference for U.S. space launch survival. A cost saving launch facility near the equator makes sense when one considers that geostationary satellites will be needed for decades to come.

Recommendation 4. Reduce the size and weight of future military satellites to conform with the size and weight of commercial satellites. This would benefit both the U.S. military and commercial launch sectors by providing common designs.

Military payloads have had the luxury of being designed with little concern for size and weight, which means that military payloads were seldom the same size and weight as commercial payloads. The Titan 3 was designed over thirty years ago, and is capable of carrying military payloads that are many times larger than most commercial payloads. The Titan 4 is also a very heavy lifter and is capable of carrying more than twice the weight of today's largest commercial payloads. By scaling back military satellites, common spacecraft can be used for launching both military and commercial payloads.

Recommendation 5. Continue and encourage the split of military and civilian space launch programs in order to provide the commercial sector enough freedom to make competitive choices and react quickly enough to catch commercial opportunities. Add a civilian contingent to both the U.S. Space Command management structure and the Pentagon with authority to influence military decisions that concern commercial launch issues.

The survival of U.S. commercial launch programs is in the hands of the Department of Defense until commercial programs can become autonomous. Ground operations, launch facilities, and space policies are largely government controlled, even though each of the three major launch companies (General Dynamics, McDonnell Douglas, and Martin Marietta) have their own commercial divisions and manufacture their own spacecraft. Too many military decisions are being made that negatively impact the future of the U.S. commercial launch business. Until commercial launch companies can break away from military entanglements, they will be unable to make the required decisions to ensure a future in the world's commercial launch market. On the other hand, selective Department of Defense funding of launch upgrades and a new launch site could establish a secure future for the U.S. commercial launch program.

In conclusion, unless something is done quickly to improve U.S. launch capabilities, it will never "catch-up" with the world's first commercial launch company, Arianespace. The U.S. government created the space sector and must ensure a smooth and effective split from the emerging commercial space program, in order to regain world dominance. Ariane, which is beginning to exercise significant influence on international trade rules, will fight any subsidized launch vehicles. This means U.S. government and commercial sector ties must be severed. However, the Department of Defense must consider commercial space launch interests when making decisions. Ariane provides an excellent "bench mark" for the U.S. to base future launch vehicle upgrades. If the U.S. sets the target of first equaling, and then surpassing, Ariane by incorporating these recommendations, the U.S. could once again dominate the world commercial launch market.